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SEASONAL FEEDING HABITS, GROWTH, AND MOVEMENT OF STEELHEAD TROUT IN THE LOWER MOKELUMNE RIVER, CALIFORNIA

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I examined the stomach contents of 179 steelhead, *Oncorhynchus mykiss*, and sub-dermally tagged 267 steelhead that were sampled seasonally from the lower Mokelumne River, in 1998 and 1999. Post-yearling (1+) steelhead fed primarily on hydropsychid larvae, chironomid pupae, zooplankton (primarily daphniids), and baetid subimago and nymphs. Although steelhead supplemented their diets with small terrestrial mammals, crayfish, and several species of fish (≥ 20 mm TL), the estimated mean prey item size ingested was less than 5 mm. Mean prey size did not change relative to fish lifestage or fork length in either year. However average number of prey items per stomach increased with fork length of fish. Steelhead occasionally ingested benthic organisms dislodged from feeding and spawning activities of other salmonids. Small mats of filamentous algae were also consumed throughout the year, presumably for the zooplankton and early instar insects entrained in the material. Overall, the index of fullness for steelhead was less during the 1999 season than in 1998. This decrease may be attributed to cooler water temperatures. Steelhead grew 0.32 mm/day on average (min: 0.04; max: 0.92). Sub-adult steelhead were more mobile than adult fish and were recaptured up to 2.5 km from original tagging sites.

INTRODUCTION

North American steelhead, *Oncorhynchus mykiss*, populations have experienced significant reductions in the past century. Estimated spawners in the Central Valley of California have declined from over 40,000 fish in the mid-1950s to less than 10,000 by the early 1990s (Hallock et al. 1961, Hallock 1991, McEwan and Jackson 1996). Concerns over the fate of Central Valley steelhead required the National Marine Fisheries Service to list this population as threatened under the Endangered Species Act in 1998.

During the last 40 years, field studies have enhanced our basic knowledge of life history and ecological requirements of steelhead. Food availability, feeding rates, and prey selection are important considerations in restoration and management of these fish and general steelhead diet information is well documented in the literature (Shapolov and Taft 1954, Johnson and Ringler 1980, Johnson 1985, Bilby et al. 1998). Sasaki (1966), and Merz and Vanicek (1996) have described diets of sub-yearling

steelhead in two Central Valley rivers. However, steelhead may spend several years in river systems before migrating to the ocean and are known to feed when returning to fresh water (Hallock et al. 1961). Currently, there is little information regarding diets, growth, or movement of age 1+ steelhead residing in anadromous streams of the Central Valley.

This report documents seasonal diet variations, growth, and movement of age 1+ steelhead in a regulated Central Valley stream, the lower Mokelumne River (LMR), during two different water years.

STUDY AREA

The Mokelumne River is a modified system that drains approximately 1,624 km² of the central Sierra Nevada. The LMR is approximately 54 km of regulated river between Camanche Dam, the downstream-most non-passable barrier to anadromous fish, and its confluence with the Sacramento-San Joaquin Delta. The study area, between Camanche Dam and Lake Lodi (Fig. 1), is characterized by alternating bar complex and flatwater habitats, and is above tidal influence, with a gradient of approximately 0.17 m/km. The drainage consists of 87 km² of mostly agricultural and urbanized land. Several small streams and storm drains enter the lower river.

At least 35 fish species occur in the LMR (Merz 2001). The most abundant native species, in addition to steelhead trout, are chinook salmon, *O. tshawytscha*, prickly sculpin, *Cottus asper*, and Sacramento sucker, *Catostomus occidentalis*. Abundant non-native fish include western mosquitofish, *Gambusia affinis*, largemouth bass,

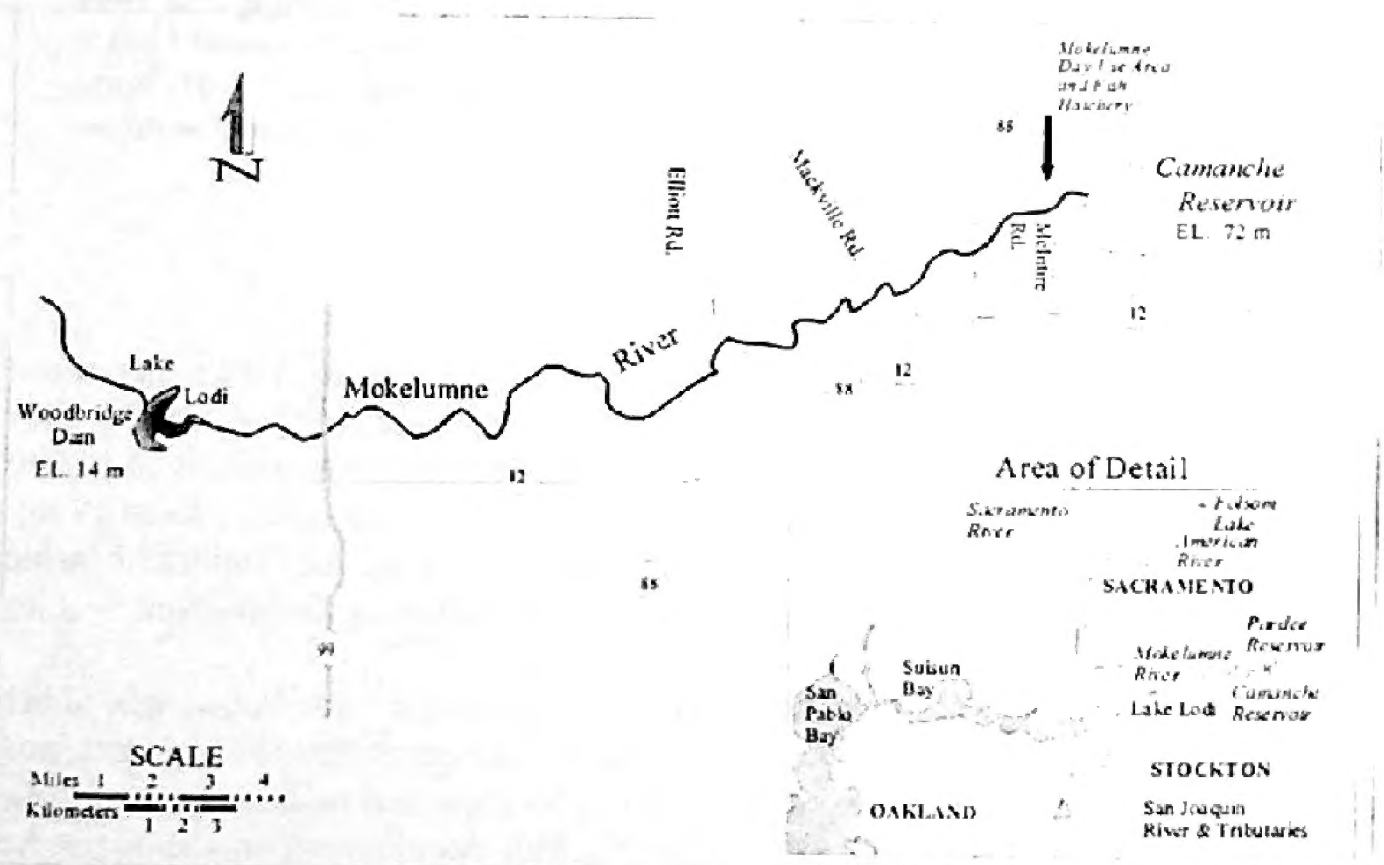


Figure 1. The lower Mokelumne River between Camanche Dam and Woodbridge Dam, San Joaquin County, California. The three reaches of river designated for this study are indicated.

Micropterus salmoides, bluegill, *Lepomis macrochirus*, and golden shiner, *Notemigonus crysoleucas*. The LMR steelhead population is supplemented by Mokelumne River Hatchery production and fish imported from the Feather River and Nimbus hatcheries. Presently, hatchery steelhead are released only below Woodbridge Dam, a seasonal flashboard dam used to fill Lake Lodi (Fig. 1). Numerous rainbow trout, *O. mykiss*, of various origins are regularly planted in the river above Camanche Dam. California hatchery production steelhead have been adipose fin-clipped since 1997. However, hatchery rainbow trout are not clipped.

During the 1998 study period, mean daily discharge from Camanche Dam peaked at 103.9 m³/s on 14 February and again at 101.4 m³/s on 30 June. Flows dropped to 8.8 m³/s on 3 September 1998 (Fig. 2). Flows during 1999 peaked at 87.8 m³/s on 21 February and reached a minimum of 9.2 m³/s on 7 September. Water temperatures ranged from 9.1 °C in February to 15.5 °C in November 1998 (annual mean 13.2 °C) and 9.1 °C in February to 15.3 °C in September 1999 (annual mean 12.2 °C) (Fig. 3).

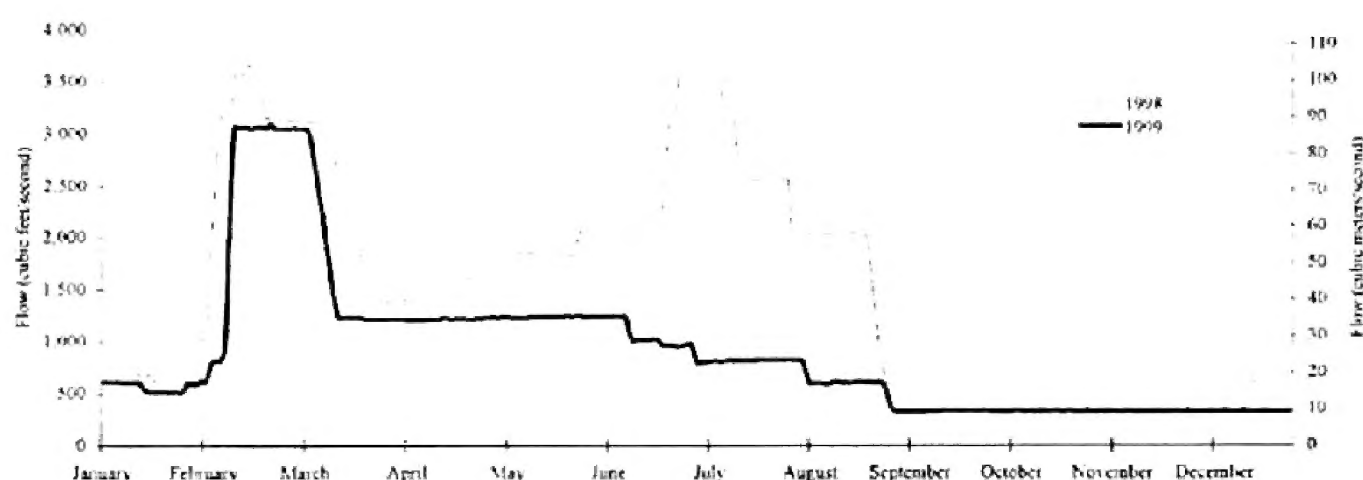


Figure 2. Mean daily discharge from Camanche Dam into the lower Mokelumne River from 1 January to 31 December 1998 and 1999.

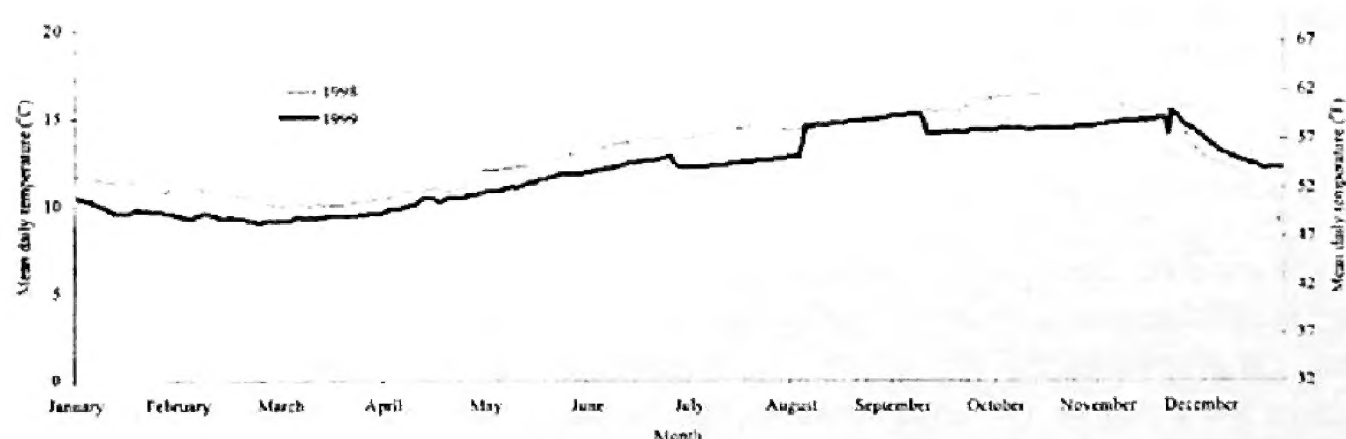


Figure 3. Lower Mokelumne River mean daily temperature measured directly below Camanche Dam from 1 January to 31 December 1998 and 1999.

METHODS AND MATERIALS

The Mokelumne River above Lake Lodi was separated into three reaches based on stream gradient and substrate characteristics (Fig. 1). Habitat types were identified and assigned to one of five habitats (modified from Bisson et al. 1981): 1) channel pools (unbroken surface, slow velocity, deep water); 2) glides (moderately shallow water with an even flow that lacked pronounced turbulence); 3) runs (rippled surface, fast velocity, shallow water); 4) riffles (stream bed substrate protruding through water surface); and 5) off channel pools (slow, deep water adjacent but contiguous to the main channel).

Steelhead were sampled between Lake Lodi and Camanche Dam during seasonal fish community surveys. Sampling was performed for 3 days the 1st week of January, April, August, and October 1998 and 1999. Sampling occurred between 0900 and 1500 hr with a 5.5-m electrofishing boat at representative habitats from each reach. The minimum target sample size was 13 fish per season, based on preliminary stomach samples (Hurtubia 1973). All specimens were measured in the field to the nearest 1 mm fork length (FL). Life stages of captured fish were identified and assigned to one of four stages: 1) Parr (darkly pigmented, distinct parr marks, no silver coloration, scales firmly set); 2) Silvery parr (parr marks visible but faded, intermediate degree of silvering); 3) Smolt (parr marks highly faded or absent, bright silver or nearly white coloration, scales easily shed (deciduous)); and 4) Adult (FL > 250 mm, no parr marks, well developed coloration, including dark spots above the lateral line, scales not easily shed). Stomachs of fish greater than 120 mm FL were evacuated following the methods described in Bowen (1983), Light et al. (1983), and Giles (1980). Stomach samples were immediately preserved in an 80-85% ethyl-alcohol solution, packed in ice, and transported to the laboratory for analysis. A sub-set of steelhead was marked to track movement and growth within the LMR. Liquitex brand fluorescent acrylic paints and Higgins brand non-waterproof india ink were injected with a 26-gauge needle and a 3-cc syringe using different mark locations and colors to distinguish individual fish following the methods described by Fay and Pardue (1985). Combinations of color and injection locations (base of pectoral, pelvic, and caudal fins) were used to identify marking date and capture location and fish were released on site. Tracking of marked fish was accomplished by steelhead observations during seasonal electrofishing, seining, and angler surveys and two rotary screw traps operated in the lower Mokelumne River below the Woodbridge Irrigation District Dam (WIDD) (Fig. 1).

Laboratory Analysis

Stomach contents were hand-sorted in the laboratory under a dissecting microscope and magnifying illuminator. Food items were identified to family for aquatic organisms and order for terrestrial organisms; life stages (larva, pupa, or adult) were determined. Adult Ephemeroptera, Trichoptera, Plecoptera, and Diptera were classified as terrestrial. Food items were further categorized into the following size classes: class 1 = <2 mm;

class 2 = 2-7 mm; class 3 = 8-13 mm; class 4 = 14-20 mm; class 5 = >20 mm (Baldrige¹ et al. 1987). Prey lengths were then estimated using the mean length for each size class.

Because most food items removed from fish stomachs were disarticulated or partly digested, representative samples of whole prey items from benthic, drift, and seine samples (Merz and Workman² 1998; Merz 1998³) were used to estimate dry biomass of stomach contents by oven drying selected samples of each taxon at 70 °C for 24 h to constant weight and then weighing the samples (Bowen 1983). As many of these organisms were extremely small (less than 0.0001 g), groups of 20-50 organisms of a particular taxon from each sample were dried, depending on how many could be obtained. Mean weight was calculated for the taxon, lifestage, and size class by dividing the dry weight of the group by the number of individuals. Mean weight was multiplied by numbers of the same taxon found in fish stomachs. Dry weight sums were used to estimate seasonal diet composition of steelhead trout following the methods of Johnson and Johnson (1981). Diet was pooled on a seasonal basis and analyzed by frequency of occurrence, numeric, and gravimetric (dry weight) methods (Bowen 1983). To assess the relative importance of food items, an index of relative importance (IRI) (Hyslop 1980) was calculated for each food category:

$$IRI = (\%N + \%W) \times \%O,$$

where,

- %N = a food item's percentage of the total number of organisms ingested,
- %W = a food item's percent of the total weight of food ingested, and
- %O = a food item's percentage frequency occurrence in all stomachs that contained food.

To make dietary comparisons, IRI values of each food item were converted to percentages based on total IRIs for each season (Merz and Vanicek 1996).

An overall index of fullness (IF) for each sample season was calculated by dividing the mean weight of stomach contents for that period by mean FL of all steelhead trout examined that contained food and multiplying this value by 100 (Merz and Vanicek 1996).

¹Baldrige, J. E., T. K. Studley, T. P. Keagan and R. F. Franklin. 1987. Response of fish populations to altered flows project. Study Plan. Entrix, Inc., Walnut Creek, California, USA.

²Merz, J.E. and M.L. Workman. 1998. Lower Mokelumne River fish community survey. Report, East Bay Municipal Utility District, Fisheries and Wildlife Division, Lodi, California, USA.

³Merz, J. E. 1998. An evaluation of spawning gravel enhancement projects in the lower Mokelumne River, California. Report, East Bay Municipal Utility District, Fisheries and Wildlife Division, Lodi, California, USA.

Statistical Methods

A paired t-test was used to compare mean daily river flow and water temperature immediately below Camanche Reservoir between years and to compare mean indices of fullness between years (Zar 1996). Estimated mean prey size was compared to steelhead FL and sample year using the JMP linear regression model function, which performs an analysis of variance (ANOVA) (Sall et al. 2001). ANOVA was also used to compare mean number of ingested prey items and life stage and FL of steelhead. Chi-square (1-way test) was used to compare growth to lifestage of tagged fish and was also used to compare recapture location and lifestage of steelhead (Sall et al. 2001).

RESULTS

Mean daily releases from Camanche Dam were significantly higher in 1998 than 1999 ($t = -16.11$; $df = 364$; $P < 0.0001$) (Fig. 2). Mean daily water temperatures released from Camanche Dam were significantly cooler in 1999 than 1998 ($t = -21.2$; $df = 365$; $P < 0.001$).

The stomach contents of 179 steelhead were examined (Table 1). Adequate numbers of stomachs (minimum 13) were sampled except during the summer of 1998, when only three were sampled. Seasonal mean FL varied from 193 mm in fall to 380 mm in winter 1998 and 193 mm in fall to 252 mm in spring 1999. On the basis of length frequency groupings, most steelhead sampled appeared to be in their second (age 1+) to fourth (age 3+) year. Only two adipose fin clips were observed in 611 fish during the study period, indicating very few hatchery steelhead rear in the river above Woodbridge Dam.

Table 1. Seasonal sample size and mean fork lengths (FL) of steelhead trout from the lower Mokelumne River, 1998 and 1999.

<i>Year</i>		<i>Winter</i>	<i>Spring</i>	<i>Summer</i>	<i>Fall</i>
1998	Sample size	13	14	3	35
	Minimum FL	137	215	145	121
	Maximum FL	380	279	253	442
	Mean FL	248	238	206	193
	SD	66	25	55	83
1999	Sample size	62	22	14	16
	Minimum FL	118	170	92	130
	Maximum FL	435	365	332	340
	Mean FL	196	252	220	193
	SD	68	41	69	68

Composition of Diets

Steelhead trout fed on a wide variety of food items including stonefly (Plecoptera) nymphs, terrestrial ants (Hymenoptera), small fish, and mice (*Peromyscus* sp.). However, the major portions of their diets, in order of relative importance, were hydropsychid caddisfly larvae, chironomid pupae, baetid mayfly nymphs and subimago, and zooplankton (primarily daphniids). This general pattern occurred in both years (Table 2).

Seasonal diet trends of LMR steelhead (Fig. 4 and 5) show that aquatic insects were a major food item throughout all seasons, especially during 1999. Of these, trichopterans, chiefly hydropsychid larvae, were important for all seasons. In contrast, aquatic dipterans (mostly chironomid pupae) were a dominant food source only during the fall of 1998 and all seasons of 1999. Aquatic ephemeropterans (mostly baetid subimago) were a dominant food in fall 1998 and winter and fall 1999 (Fig. 4). Zooplankton provided high IRI values for steelhead trout only during winter 1998 and spring of both years (Fig. 4).

Piscivory

Although fish were found in the diets of steelhead trout throughout the study period, %IRI of prey fish was high only during the winter of 1998, when collective prey fish IRI was 39% (Fig. 4).

Fish eggs, juveniles, or adults were found in 10% of steelhead trout stomachs sampled. Sculpin were the most common fish (including eggs) observed in stomachs, followed by chinook salmon eggs and fry, and cyprinid and Sacramento sucker eggs and juveniles. Chinook salmon fry (34-39 mm FL) were found in the stomachs of steelhead trout (≥ 147 mm FL) and had the highest %IRI value of all fish ingested. Adult prickly sculpin (43-52 mm SL) were observed in the stomachs of steelhead trout ≥ 175 mm FL, but were less common.

Feeding relative to prey size

The estimated mean prey item size ingested by steelhead trout captured was 4.78 mm (SD 1.76). The seasonal mean prey item size did not change significantly relative to fork length of the fish sampled in either year (Fig. 6).

Feeding relative to fish lifestage and size

Mean estimated prey item size did not change significantly relative to steelhead lifestage in either year ($F = 1.97$; $df = 4, 130$; $P = 0.100$). However, mean number of prey items was significantly related to fish size in 1998 ($F = 15.29$; $df = 7$; $P = 0.008$) and 1999 ($F = 18.75$; $df = 11$; $P = 0.001$) (Fig. 7).

Table 2. Major food items of steelhead trout in the lower Mokelumne River, 1998 and 1999, presented as percent Index of Relative Importance (IRI%) for each year

<i>Prey Item</i>	<i>Life Stage</i>	<i>1998</i>	<i>1999</i>
Aquatic			
Invertebrates			
Ephemeroptera			
Baetidae	nymphs	2.2%	6.1%
	subimago	10.8%	4.6%
Other	nymphs	0.4%	0.6%
	subimago	0.0%	0.4%
Diptera			
Chironomidae	larvae	1.8%	2.4%
	pupae	21.3%	48.4%
Other	larvae	0.1%	0.5%
	pupae	0.0%	0.3%
Trichoptera			
Hydropsychidae	larvae	32.0%	20.5%
	pupae	3.7%	2.1%
Other	larvae	0.1%	0.5%
	pupae	0.2%	1.7%
Oligochaeta		0.8%	0.6%
Zooplankton		15.0%	4.2%
Aquatic Invertebrate Sub-total		88.4%	92.8%
Fish			
Salmonidae	eggs	0.6%	0.2%
	juveniles	0.0%	3.5%
Cottidae	eggs	1.4%	0.0%
	larvae & adults	2.2%	0.2%
Other	eggs	0.0%	0.0%
	larvae & adults	0.5%	0.1%
Unidentifiable		0.3%	0.1%
Fish Sub-total		5.5%	4.0%
Terrestrial			
Arthropods		1.5%	2.4%
Others		4.6%	0.8%
Grand Total		100.0%	100.0%

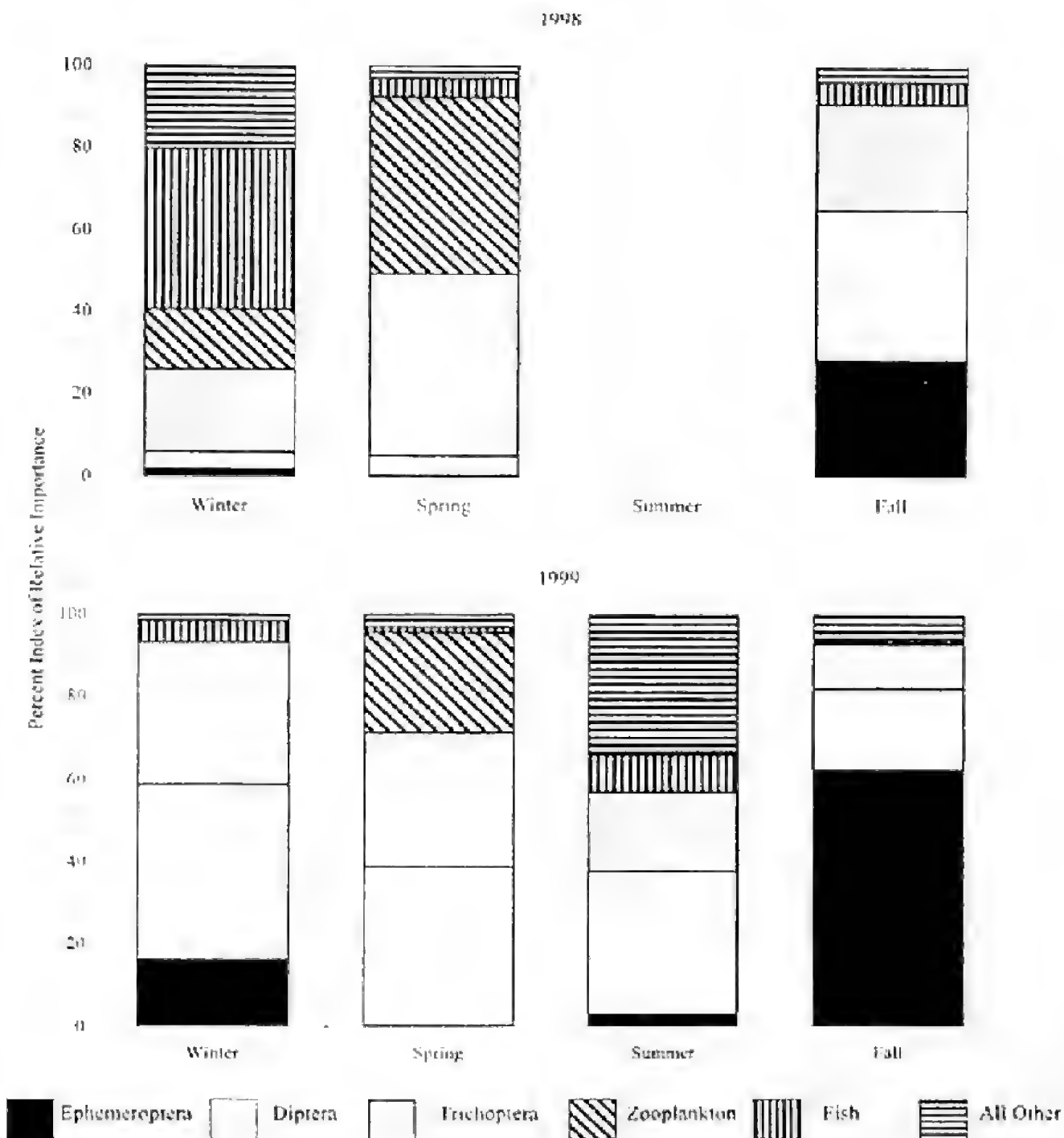


Figure 4. Major food items of steelhead in the lower Mokelumne River by season, 1998 and 1999. Food items are presented as percent Index of Relative Importance (IRI%) for each season.

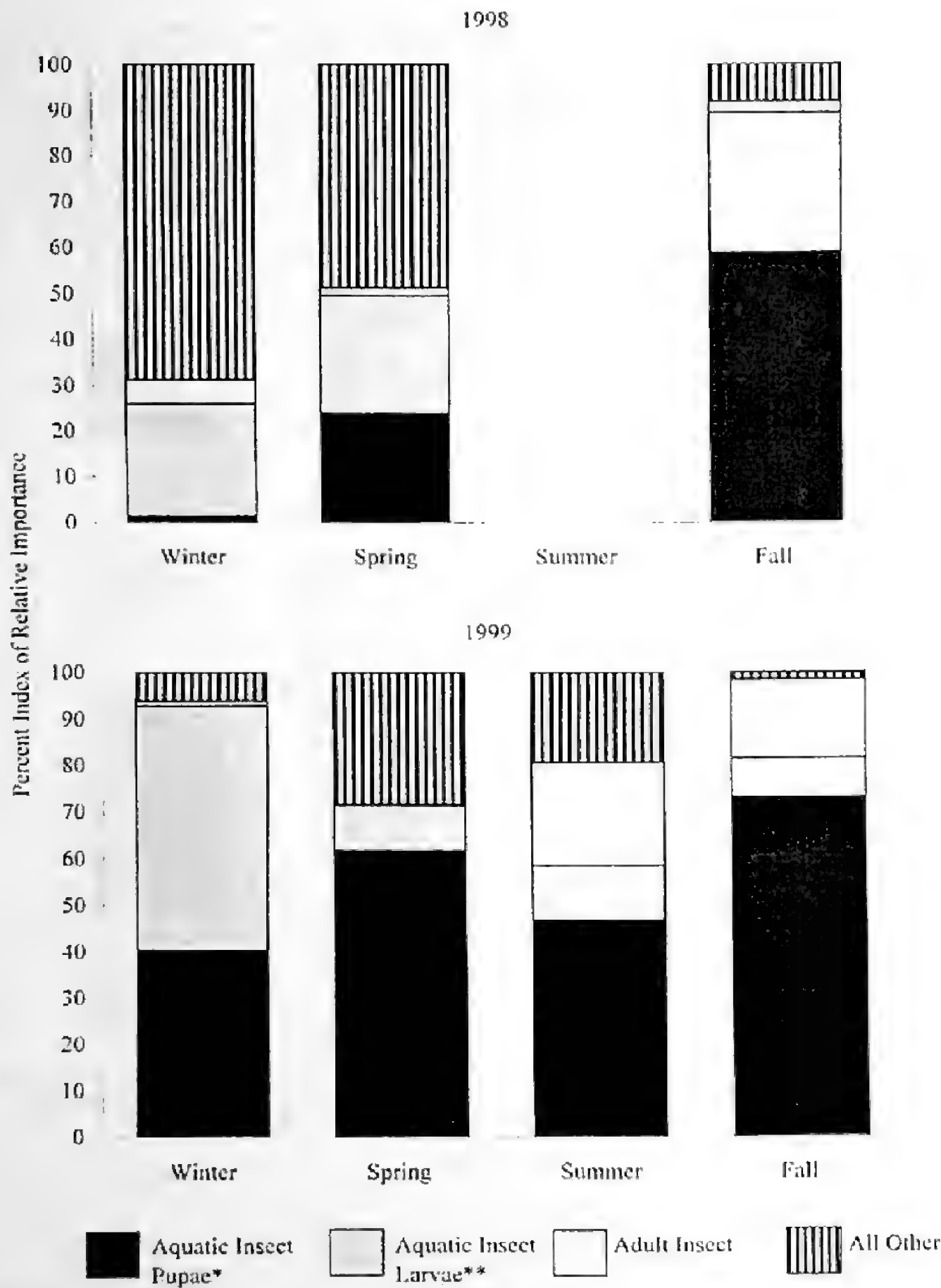


Figure 5. Life stages of organisms ingested by steelhead trout in the lower Mokelumne River by season, 1998 and 1999. Life stages are presented as percent Index of Relative Importance (IRI%) for each season.

*Pupae include Ephemeroptera subimago **Larvae include Ephemeroptera nymphs

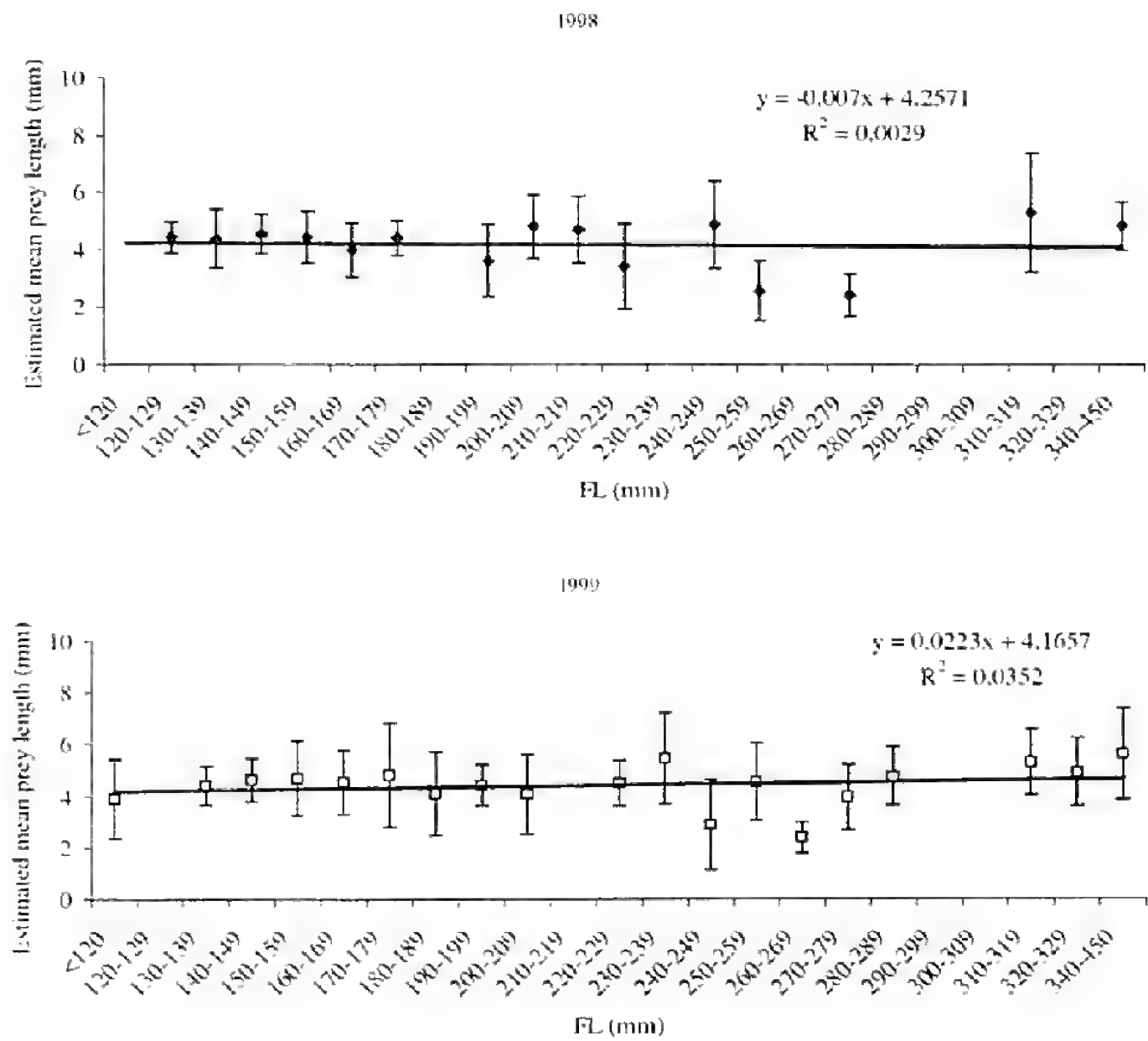


Figure 6. The relationship of Mokelumne River steelhead trout forklength (FL) and food size ingested, 1998 and 1999, as indicated by mean food item size, trend line and one standard deviation

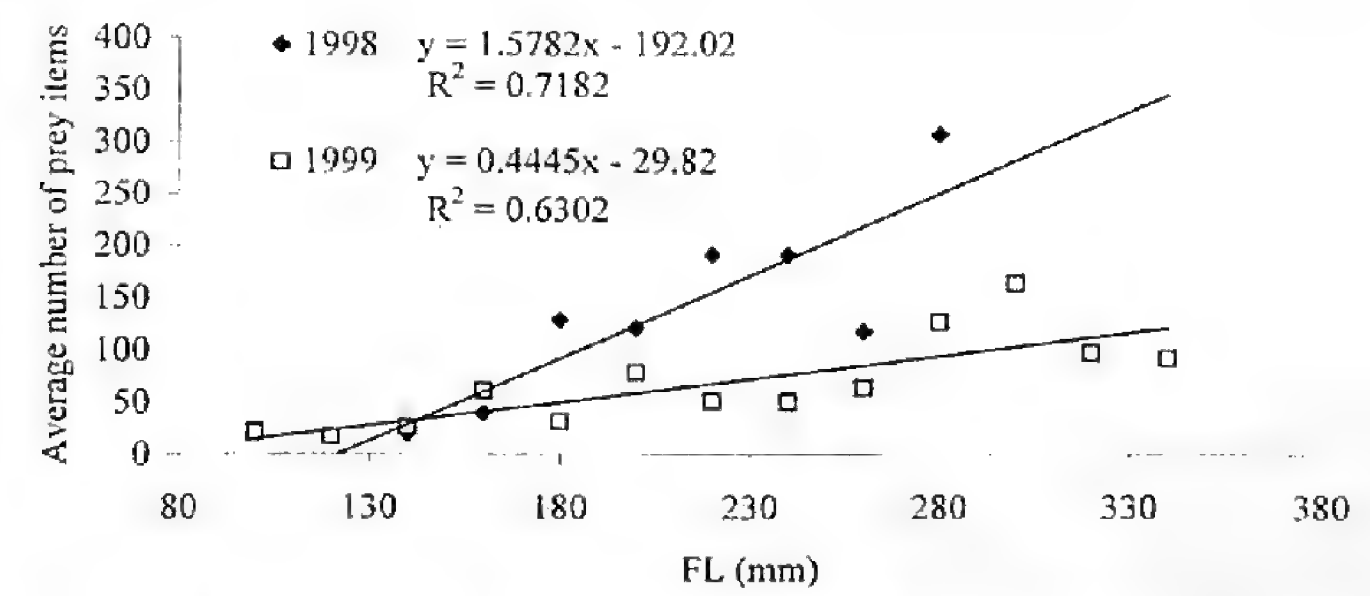


Figure 7. Average number of prey items per steelhead stomach in 1998 and 1999. Equations for simple linear regression are indicated for 1998 and 1999.

Feeding Activity

Seasonal feeding activity, as indicated by Index of Fullness (IF), suggests greatest feeding activity occurred during winter in both years (Fig. 8). Seasonal IF in 1999 was significantly less than in 1998 (t -ratio = -3.26; df = 3; P = 0.047). Index of Fullness was not significantly related to FL in either year (F = 0.0260; df = 2; 136; P = 0.97). However, IF for each size of fish was significantly less in 1999 (F = 9.89; df = 1, 137; P = 0.002). Of the 179 steelhead trout stomachs sampled, only one (0.6%) empty stomach was observed from a 380-mm FL adult male releasing milt in winter 1998.

Mats of filamentous algae were observed in 43 (24%) of the stomachs sampled. During fall 1998 and winter 1999, 18 (10%) of the stomachs sampled contained chinook salmon and steelhead trout eggs. Interestingly, bird feathers were found in 15 (8%) of the stomachs sampled. Small mammal hair (excluding one intact mouse) was found in two (1%) steelhead trout stomachs. Thirty of 288 (10%) steelhead captured by electrofishing during this study had distinct hook scars, including fishing line protruding from mouths.

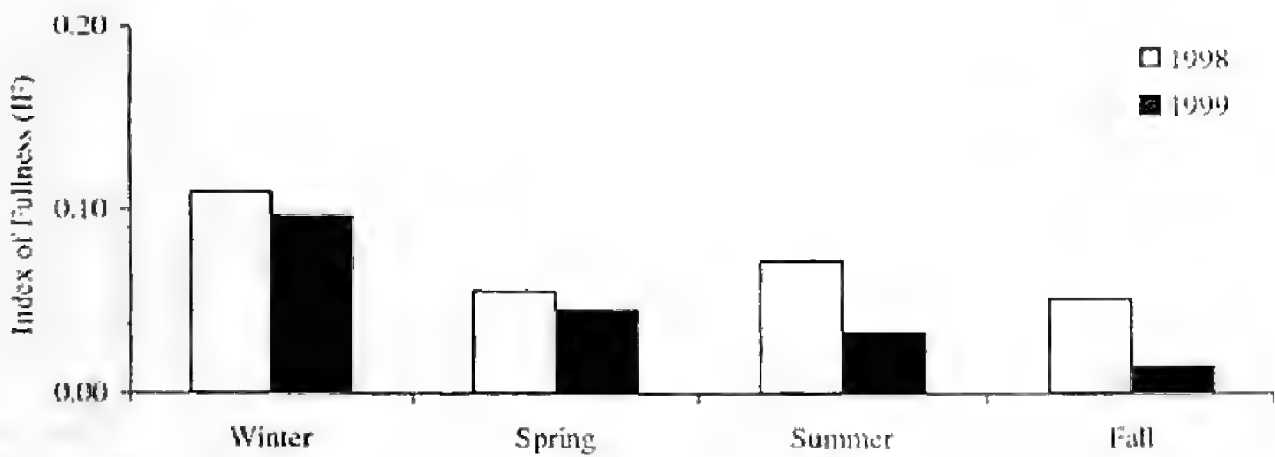


Figure 8. Seasonal feeding patterns of steelhead trout in the lower Mokelumne River, 1998-1999, as indicated by Index of Fullness (IF).

Fish Dispersal and Growth

A total of 267 steelhead was tagged during the 2-year study, including two adipose fin-clipped fish. Of these, 22 (8 %) were recaptured (Adult = 6; Smolt = 2; Silvery/parr = 9; Parr = 5) (Table 3) by electrofishing (21), seine (1) and creel surveys (1) through July 2001. No fish were re-captured by rotary screw trap nor were any adipose fin-clipped fish re-captured. Recaptured steelhead were observed anywhere from 5 to 985 days after tagging (mean = 269 days). Average fish growth was 0.32 mm/day (min = 0.04; max = 0.92). Smaller fish tended to grow more quickly than larger fish (Table 3). However, no significant difference was observed for daily growth between lifestages (F = 1.269; df = 21; P = 0.315). While all recaptured adult steelhead were observed at their initial tagging sites, a significant number of tagged parr, silvery/parr, and smolts

Table 3. Growth rates of tagged steelhead in the lower Mokelumne River, California.

Tagged			Recapture			Growth (mm)	Total Days	Growth/day (mm)	Degree Days	Average Temperature (°C)
Date	FL (mm)	Lifestage*	Date	FL (mm)	Lifestage*					
11/9/1998	80	P	7/20/2000	231	AD	151	985	0.15	12,497	12.7
11/10/1998	160	P	1/14/1999	163	SM	3	65	0.05	809	12.5
11/10/1998	135	P	1/19/1999	141	SP	6.5	70	0.09	858	12.3
5/14/1998	34	P	5/26/1998	45	P	11	12	0.92	169	13.0
5/14/1998	32	P	5/26/1998	42	P	10	12	0.83	169	13.0
1/21/1999	151	P	7/28/1999	236	SP	85	188	0.45	2,033	10.8
Average:	99		Average:	143		Average:		0.42		
12/16/1998	145	SP	1/19/1999	158	SP	13.5	34	0.40	357	10.5
7/27/1999	258	SP	10/23/2000	320	AD	62	455	0.14	6,093	13.4
1/20/1999	224	SP	1/23/2001	386	AD	162	368	0.44	4,545	12.4
4/27/1999	245	SP	7/27/1999	275	SP	30	93	0.32	1,098	11.8
1/14/1999	138	SP	1/19/1999	138	SP		5	0**	57	11.5
1/19/1999	161	SP	7/28/1999	197	SP	36	195	0.18	2,335	12.0
4/27/1999	240	SP	7/27/1999	299	SP	59	88	0.67	1,098	11.9
1/14/1999	140	SP	1/19/1999	140	SP		5	0**	57	9.6
5/1/2000	207	SP	7/20/2000	240	SP	33	80	0.41	1,056	13.2
Average:	195		Average:	239		Average:		0.37		
11/9/1998	277	SM	1/21/1999	310	AD	33	73	0.45	932	12.8
1/20/1999	271	SM	7/20/2000	320	SM	49	547	0.09	6,742	12.3
Average:	274		Average:	315		Average:		0.27		
11/3/1998	354	AD	11/9/1998	354	AD		7	0**	115	16.4
11/9/1998	410	AD	7/2/1999	420	AD	10	234	0.04	2,633	11.3
5/15/1997	235	AD	11/9/1998	352	AD	117	543	0.22	2,618	14.6
7/27/1999	240	AD	10/23/2000	333	AD	93	455	0.20	6,093	13.4
7/27/1999	302	AD	10/23/2000	333	AD	31	452	0.07	6,093	13.5
Average:	308		Average:	358		Average:		0.13		

*P = parr; SP = silvery parr; SM = smolt; AD = adult

**Fish recaptured 7 days or less after tagging were excluded from growth averages

were recaptured upstream and downstream of the original tagging sites (min = 0.8 km; max = 2.5 km). When comparing re-capture locations of adult and sub-adult steelhead recaptured at least 7 days after tagging, a significantly higher number of juveniles were captured at sites other than the original tagging location ($G^2 = 7.18$, $df = 20$, $P = 0.007$).

DISCUSSION

The diet of LMR steelhead trout was composed chiefly of immature stages of aquatic insects, similar to what has been reported in other studies (Shapovalov and Taft 1954, Johnson and Johnson 1981, Angradi and Griffith 1990, Merz and Vanicek 1996). However, due to the opportunistic feeding behavior displayed by steelhead trout (Byan and Larkin 1972, Moyle 1976, Barnhart 1986), a variety of other prey items momentarily swamped their diets, as can be seen in the consumption of salmonid eggs and juveniles in fall and winter 1998 (Fig. 4). Steelhead trout were observed actively feeding downstream and amongst spawning chinook salmon and other steelhead trout. During this time, in addition to salmonid eggs, large numbers of hydropsychid (Trichoptera) larvae and pupae were observed in sampled steelhead trout stomachs, presumably dislodged from the benthos by spawning activity.

While several aquatic insects appear to play an important role in the diets of LMR steelhead trout, it appears that these fish may rely on pupating and emerging individuals during certain periods. Specifically, Diptera pupae and Ephemeroptera nymphs undergoing transformation (subimago) provided over 50% of relative IRI for steelhead trout in fall of both years (Fig. 5). Large numbers of exoskeletons from emerging hydropsychids and heptageniids were also observed sporadically in individual trout, which were apparently keying in on these items. While IRI values were not calculated for ingested exoskeletons in this study, they may provide some caloric value for steelhead trout, further emphasizing the importance of pupating and emerging aquatic insects in the diets of these fish.

Angradi and Griffith (1990) reported that 30% of rainbow trout stomachs they sampled from the Snake River, Idaho contained filamentous algae. Similarly, 24% of steelhead stomachs sampled from the LMR contained mats of algae. Angradi and Griffith (1990) found a correlation between this phenomenon and number of Trichoptera larvae consumed. I also observed Trichoptera larvae in most (93%) of the LMR steelhead stomachs sampled that contained algae. Steelhead were observed during this study scraping the substrate with their sides and mouths, dislodging algae, which was either ingested by them or other trout close by. This behavior also occurred below spawning salmonids. Very early baetid instars and several species of zooplankton (≤ 1 mm TL) have been reported in algal mats sampled during benthic and drift studies within this geographic area (Merz¹ 1992, Merz⁵ 1998). This suggests steelhead trout may actively pursue algal material and may benefit by the concentration of relatively small prey items contained within the mats. This subject should be studied further.

Smith and Li (1982) found that in a California stream, increased fish size and water

¹Merz, J. E. 1992. A survey of drift and benthic communities and their use in the diet of the more abundant fish species in the lower American River. February – July, 1992. CSUS Hornet Foundation Contract FG1353. California State University, Sacramento, California, USA.

⁵Merz, J. E. 1998. Evaluation of spawning gravel enhancement in the lower Mokelumne River. Report. East Bay Municipal Utility District, Lodi, California, USA.

temperature resulted in increased standard metabolism and food demand by juvenile steelhead. Fish responded to these factors by selecting microhabitats with higher velocities, and shallower and coarser substrate to capture prey from portions of the water column substantially faster and more productive than at their resting positions. Similarly, LMR steelhead had higher IF values in 1998 than 1999 suggesting greater feeding activity during a warmer and higher flow water year (Figs. 3 and 8). While larger prey items (20 mm + TL), such as fish and crayfish occasionally appeared in the stomachs of steelhead trout, average prey size did not increase with size of fish or during the warmer water year (Fig. 6), supporting findings by Smith and Li (1982). Although this study did not specifically look at microhabitat use, adult Mokelumne River steelhead were more apt to remain in one area than juvenile fish and were observed in the same sampling sites for as much as 543 days after tagging. This is most likely due to the ability of larger fish to obtain and keep territories (Keeley and McPhail 1998; Keeley 2000).

In summary, these data suggest that while LMR steelhead trout eat a wide variety of prey items of various sizes, the majority of items ingested by several year-classes are small aquatic insects and zooplankton. Steelhead trout also ingest algal material although it is unclear whether very small prey items within the algae or the algal material itself is the purpose of this feeding behavior. River temperature influences the number, but not necessarily the size, of prey items ingested by individual fish. Mokelumne River steelhead may remain in a single habitat for up to 543 days, but this is dependent on the size and age of the fish. Further understanding of specific habitat/feeding relationships of these fish may improve restoration efforts within the Sacramento-San Joaquin System.

ACKNOWLEDGMENTS

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THE SPOTTED RATFISH, *HYDROLAGUS COLLIEI*: NOTES ON ITS BIOLOGY WITH A REDESCRIPTION OF THE SPECIES (HOLOCEPHALI: CHIMAERIDAE)

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The spotted ratfish, *Hydrolagus colliei*, is common along the west coast of the United States ranging from southern Alaska into the Gulf of California in depths ranging from near the surface to recorded depths of 913 meters. Although this species is common, and apparently abundant throughout its range, very little is known of its biology and it is not presently targeted in commercial fisheries. A diagnosis of the family Chimaeridae and redescription of *Hydrolagus colliei* based on study of 59 specimens is presented. This redescription clarifies diagnostic features of the species and is useful for distinguishing *H. colliei* from all other species of chimaeroid fishes. Discussion of the status of *Hydrolagus media*, once considered a separate species, clarifies that *H. media* is a junior synonym of *H. colliei*.

INTRODUCTION

The living chimaeroid fishes are an ancient lineage closely related to sharks and grouped with the sharks, skates, and rays in the class Chondrichthyes. Although the chimaeroids, commonly known as chimaeras or ratfishes, are like sharks, skates, and rays in possessing a cartilaginous skeleton, they are in fact quite different in overall appearance in having elongate bodies with long whip-like tails, a single gill opening on each side of the head, and smooth, scaleless skin. There are three families of chimaeroids, each distinguished by unique snout morphology. The family Callorhynchidae, found only in the southern hemisphere, is characterized by a snout that is formed into a leaf-like flap, much like the shape of a hoe or plow and projects

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anteriorly from the front of the head. There is just one genus and three species of callorhynchid fishes. The eight species in the family Rhinochimaeridae have long tapered snouts projecting anteriorly from the head and hence are commonly known as the long-nosed chimacras. The rhinochimaerids have a worldwide distribution and inhabit deep waters, generally 800 m or deeper. One species of rhinochimaerid, *Harriotta raleighana*, has been reported from deep waters off California, but it is not common (Eschmeyer et al. 1983). The family Chimaeridae is the most speciose with 22 valid species classified in two separate genera. The 7 species within the genus *Chimaera* have an anal fin separated from the ventral caudal fin by a notch, while the 15 species of *Hydrolagus* lack a separate anal fin and the ventral caudal fin is straight, extending as a fleshy ridge along the base of the tail, with no notch.

The chimacras have a worldwide distribution and some species are wide-ranging in both the Atlantic and Pacific oceans. Species of chimaeroids are typically found at depths ranging from the surface to over 2,000 m, with the greatest diversity and abundance of specimens collected at depths over 500 m. Increased fishing effort and exploratory fisheries in deep water, at or below 1,000 m, have resulted in the capture of new species previously unknown to science (Compagno et al. 1990, Hardy and Stehmann 1990, Didier and Stehmann 1996). In waters around Australia and New Zealand at least 10 new species belonging to the family Chimaeridae have been discovered (Paulin et al. 1989, Last and Stevens 1994).

Hydrolagus collieri is the most common species of chimaeroid fish found off the west coast of the United States and appears to be quite abundant throughout much of its range (Allen and Smith 1988, Quinnell and Schmitt¹ 1991, Eschmeyer et al. 1983). Other species of chimaeroids occur in deeper waters but are rarely observed (Eschmeyer et al. 1983, D. Ebert, Pacific Shark Research Center, pers. comm.). Due to movement of adults into shallower coastal waters (Quinn et al. 1980) this species is often caught by commercial as well as recreational fishermen. For the most part, *H. collieri* is considered a nuisance species primarily due to its propensity for becoming entangled in nets by either the large dorsal spine or the frontal tenaculum atop the head which is armed with rows of sharp spines. Additionally, the dorsal spine is venomous and can cause a painful wound (Halstead and Bunker 1952). There was reported to be a small fishery for ratfish livers, the oil of which is purported to be a good machine lubricant (Clemens and Wilby 1961; Kato² 1992); however, there are no targeted fisheries for any chimaeroid fishes in the United States although they are caught as bycatch in trawls.

This report includes a diagnosis of the family Chimaeridae and re-description of *Hydrolagus collieri*, the spotted ratfish, common to the west coast of North America with notes on its biology. At least one other species of *Hydrolagus* is known from deep waters off California and overlaps in range with *H. collieri*, but this species has yet to be formally described.

¹Quinnell, S. and C. Schmitt. 1991. Abundance of Puget Sound demersal fishes: 1987 research trawl survey results. State of Washington Dept. of Fisheries, progress report No. 286.

²Kato, S. 1992. Spotted ratfish. Pages 197-198 in: Leet, W.S., C. M. Dewees, C. W. Haugen, editors. California's living marine resources and their utilization. California Sea Grant, Sea Grant Extension Publication UCSGEP-92-12.

METHODS

A total of 59 specimens of *Hydrolagus collieri* was examined. Measurements were taken from preserved specimens, measured point to point using dial calipers and a tape measure, and recorded in millimeters. Standards for measurements were based on Compagno et al. (1990), Didier and Stehmann (1996), and Didier (1998). Measurements are illustrated and defined in Fig. 1. Body proportions were calculated as proportions of body length (BDL).

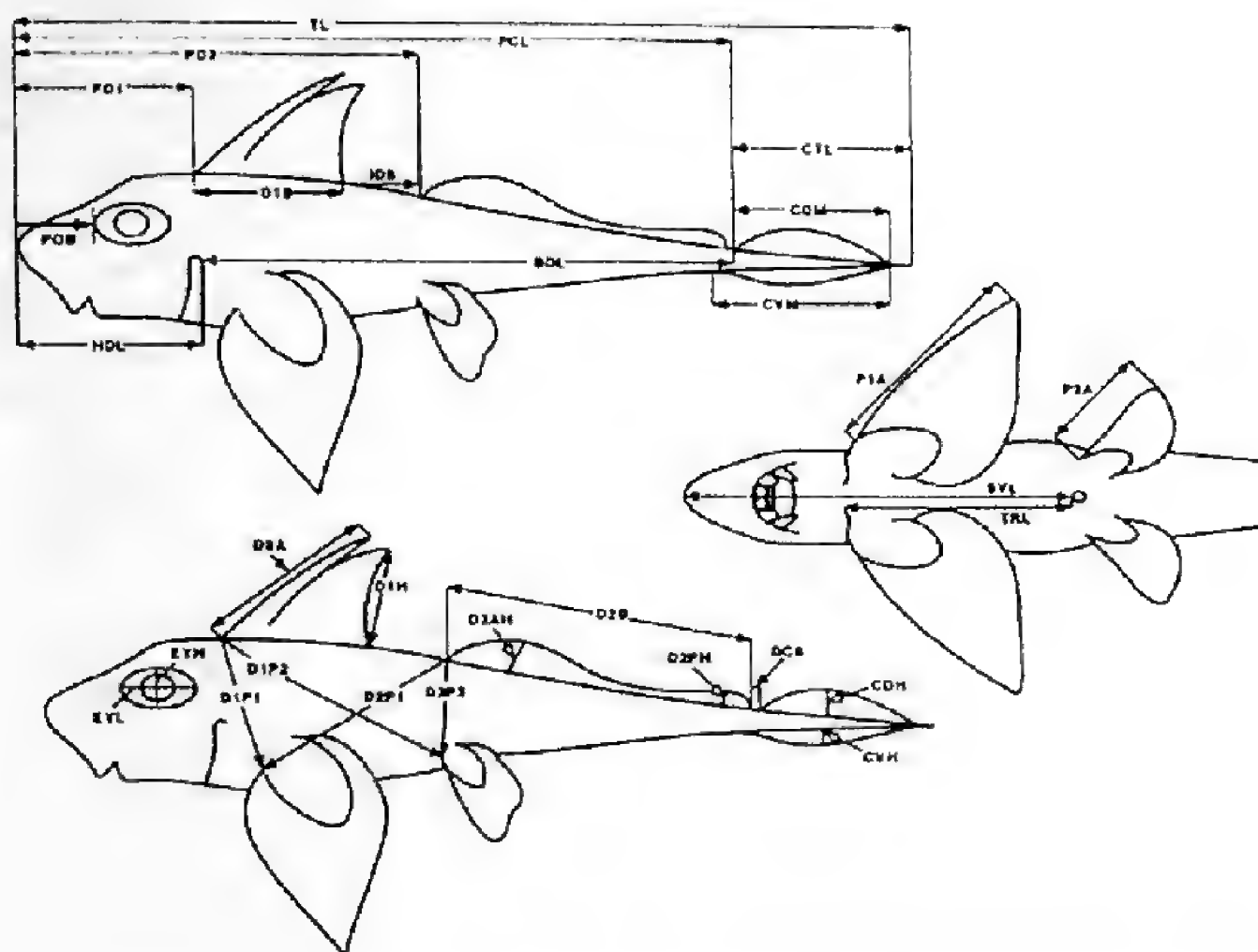


Fig. 1. Diagram of point-to-point body measurements. Some measurements are shown between parallels for ease of illustration. Abbreviations are as follows: total length (TL); precaudal length (PCL); body length (BDL); snout-vent length (SVL), distal tip of snout to cloacal opening; trunk length (TRL); pre-second dorsal length (PD2); pre-first dorsal length (PD1); preorbital length (POB); second dorsal fin base (D2B); anterior second dorsal fin, maximum height (D2AH); posterior second dorsal fin, maximum height (D2PH); first dorsal fin base (D1B); dorsal spine length (DSA); first dorsal fin, maximum height (D1H); caudal dorsal margin (CDM); dorsal caudal fin, maximum height (CDH); caudal ventral margin (CVM); ventral caudal fin, maximum height (CVH); head length (HDL); pectoral fin anterior margin (P1A); pelvic fin anterior margin (P2A); interdorsal space (IDS); dorsal-caudal space (DCS); origin of first dorsal fin to anterior edge of pectoral fin base (D1P1); origin of first dorsal fin to anterior edge of pelvic base (D1P2); origin of second dorsal fin to anterior edge of pectoral fin base (D2P1); origin of second dorsal fin to anterior edge of pelvic fin base (D2P2); eye length (EYL); eye height (EYH); pelvic claspers, total length (CLT). Measurement of the pelvic claspers is not shown.

Specimens were examined from the following collections: Academy of Natural Sciences, Philadelphia, Australian Museum, Sydney, Field Museum of Natural History, Hokkaido University Museum of Zoology, Museum of Comparative Zoology, Muséum national d'Histoire Naturelle, Paris, and University of Washington. The largest holdings of specimens from California are in the California Academy of Sciences and the Los Angeles County Museum; however, visits to these collections have not yet been possible and shipping of a large enough sample for comparison is somewhat challenging due to the large size and numbers of specimens. Museum abbreviations follow Leviton et al. (1985).

RESULTS

Family Chimaeridae, Bonaparte, 1831 Shortnose chimaeras

Cartilaginous fishes with a large head, blunt snout, and somewhat compressed, elongate bodies with tail tapering to an elongate filament. Size ranges from slender, medium-bodied fish, adults 40 - 80 mm total length, to massive fish over 1 m in length with huge heads and robust, fleshy bodies. Eyes are large and prominent, bright green in fresh specimens. Snout fleshy and bluntly pointed at the tip. Skin smooth, often deciduous, flaking off in patches after capture. Gills covered by a fleshy operculum with only a single gill opening present anterior to pectoral fins; no spiracle present. Mouth small, ventral, connected to nostrils by deep grooves. Teeth in the form of three pairs of non-replaceable tooth plates with two pairs in the upper jaw, and a single pair in the lower jaw. Tooth plates robust with patches of dense hypermineralized tissue that appears as ridges and bumps on the surface. Pectoral and pelvic fins broad with delicate external fin webs supported by cartilaginous rays (ceratotrichia). Lateral line canals appear as open grooves on the head and sides of body; canals on the snout with large dilations. Two dorsal fins, the first erectile, preceded by an elongate, serrate spine that in some species is known to be toxic; the second dorsal fin elongate and spineless. Tail with dorsal and ventral lobes of nearly equal size (diphycercal), often with a slender filament extending beyond the insertion of the fin webs, the filament sometimes equal in length to the body. Adult males with bulbous, denticulate frontal tenaculum that rests in a pouch atop the head anterior to eyes; prepelvic tenaculae blade-like with 3-7 large denticles along the medial edge, hidden in pouches anterior to the pectoral fins; and pelvic claspers bifurcate with fleshy, denticulate tips. Body color usually pale to dark brown or black, darker dorsally, lighter or white ventrally, usually without distinct color pattern, but pale spots and blotches are present in some species.

Chimaerids generally inhabit deep waters and are usually found at depths greater than 200 m to over 1,000 m. They appear to live on or near muddy bottoms where they primarily feed on a variety of benthic invertebrates, as well as fishes. Most species reach sexual maturity at about 40 cm body length, with females generally larger than males. All species are oviparous. Females lay pairs of spindle-shaped eggs that are deposited on the bottom. Embryological studies indicate that development may take as long as

9-12 months. At present they are of minimal interest to fisheries and are primarily caught as bycatch in bottom trawl fisheries and may be utilized for fishmeal and other fish products. Currently, some related species in the south Pacific are commercially fished, particularly off New Zealand and Australia, and the commercial potential of species in the Atlantic is being explored.

Hydrolagus collieri (Lay and Bennett, 1839)

Figs. 2A, 3

Chimaera collieri Lay and Bennett, 1839:71, pl. 23; Dumeril, 1865:689; Günther, 1870:350; Jordan and Gilbert, 1883:55; Garman, 1904:272; Dean, 1906:7; Garman, 1911:92; Fowler, 1941:496;

Hydrolagus collieri Gill, 1862:331; Goode and Bean, 1895:32; Jordan and Evermann, 1896:95; Barnhart, 1936:14; Roedel and Ripley, 1950:82; Miller and Lea, 1972:52; Hart, 1980:66; Eschmeyer et al., 1983:59

Chimaera media Garman, 1911:91

Chimaera neglecta Ogilby, 1888:23

Type ---No type specimens are known to exist. This species is clearly defined by Lay and Bennett (1839) and there is no question regarding the stability of nomenclature; therefore, it is not necessary to designate a neotype in this case (International Code of Zoological Nomenclature, 3rd ed., article 75.2).

Diagnosis ---A small-bodied species of *Hydrolagus* unique in having the following combination of characters: blunt, gently rounded snout; head and body uniformly dark brown to reddish-brown, lighter gray ventrally with numerous small white spots on head, dorsum, and trunk, spots becoming larger on tail along lateral line canal; caudal fin lacking elongate distal filament; second dorsal fin indented at mid-length, almost divided into two parts; two separate lateral line canals (oral and preopercular) branch from the infraorbital canal and extend downward from below the eye; males with bifid claspers divided for distal 2/3 of their length, widely separated at the bifurcation (Fig. 3B).

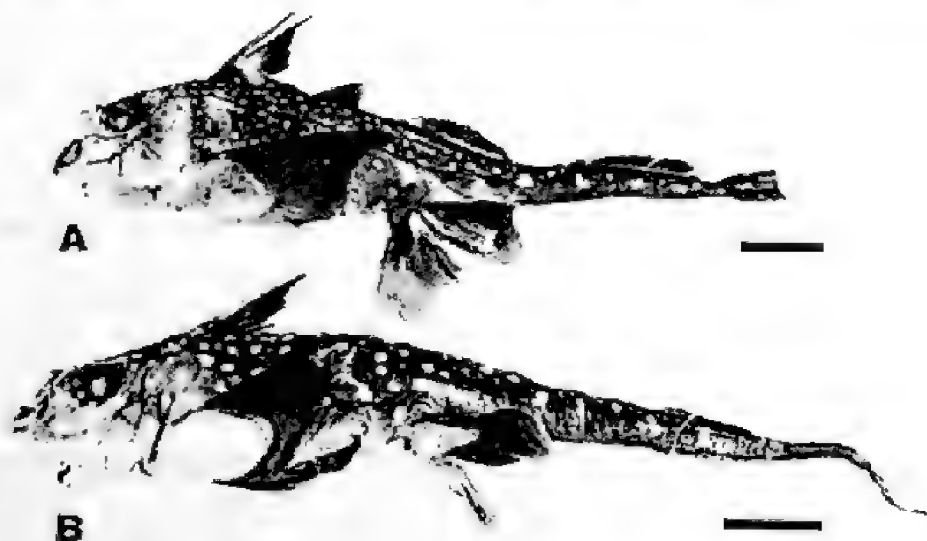


Fig. 2. Adult males of A) *Hydrolagus collieri* (ANSP 174259); tip of the tail in this specimen is broken off; and B) *Hydrolagus media* (MCZ -330); second dorsal fin is not visible due to shrinkage and folding during preservation and storage. Scale = 5 cm.

Description ---Body relatively small, tapering toward tail, with no distal caudal filament. Head with bluntly rounded snout. Eyes large, ovoid, ranging from 22-38% HDL (7-16% BDL). Body color a reddish to dark brown with silvery-blue and gold highlights, ventrally the color an even pale cream or gray color. Numerous small white spots on the head, along sides and back of the trunk with spots becoming larger on the tail along the lateral line canal.

First dorsal fin triangular, mostly straight along distal edge, light at base, dark along distal edge and preceded by a keeled spine with two rows of small serrations along distal 1/2 of posterior edge. Spine equal to or taller than first dorsal fin in adults, shorter or equal to first dorsal fin in juveniles, reaching 2/3 distance to origin of second dorsal fin when depressed. Interdorsal space large, 9-21% BDL. Second dorsal fin indented just anterior to midpoint of fin, height at indented portion ranges from roughly half maximum fin height to a narrow fin web that connects the almost completely separate anterior and posterior portions of the dorsal fin, the anterior portion taller than the longer posterior portion (D2AH 5-10% BDL, D2PH 1-7% BDL). Dorsal caudal fin slightly shorter in length and equal to or slightly greater in height than ventral caudal fin. Dorsal and caudal fins without spots, light to medium brown, darker along the distal edges. Pectoral and pelvic fins range from dark brown to grey or purplish brown. Pectoral fins stout and triangular in shape, with distal edge mostly straight, rounded along ventral edge. Pelvic fins differ in shape between adult males and females. In males, pelvic fins are slightly ovoid with distal edge indented and females have rectangular shaped pelvic fins with a straight distal edge. Juveniles, both male and female, have "female shape" pelvic fins.

Dentition ---Six tooth plates present: two vomerine and two palatine tooth plates in upper jaw, two mandibular tooth plates in lower jaw. Each incisor-like vomerine tooth plate has 4-7 tritor ridges. Palatine tooth plates flat and triangular in shape, and lie posterior to vomerine tooth plates on roof of mouth. Each has several tritors, but it was impossible to count and examine tritors in almost every specimen because the palatine tooth plates are located far back in mouth. Mandibular tooth plates firmly seated in the lower jaw, articulating at midline and curving away from each other, following anterior margin of lower jaw. Each mandibular tooth plate has 5-9 tritor ridges. Tooth plates vary from white to yellowish in color.

Lateral line canals ---Lateral line canals appear as open grooves on head and trunk (Didier 1995; Fields, et al. 1993). There is a small, distinct space between the preopercular (PO; also known as hyomandibular, Didier, 1995) and oral (O) (also known as horizontal, Didier, 1995) lateral line canals where they branch from the infraorbital (IO) canal (Fig. 3A). Trunk lateral line canal straight, slightly rising then dipping at its juncture with the otic canal.

Secondary sexual characters ---Pelvic claspers forked for 2/3 length, each branch supported by cartilage and widely separated at the bifurcation. Distal tips fleshy with a shagreen of denticles (Fig. 3B). Pre-pelvic tenacula flat, blade-like with 3-5 recurved denticles along medial edge. Frontal tenaculum slender and gently curved with large bulbous tip armed with numerous recurved denticles.

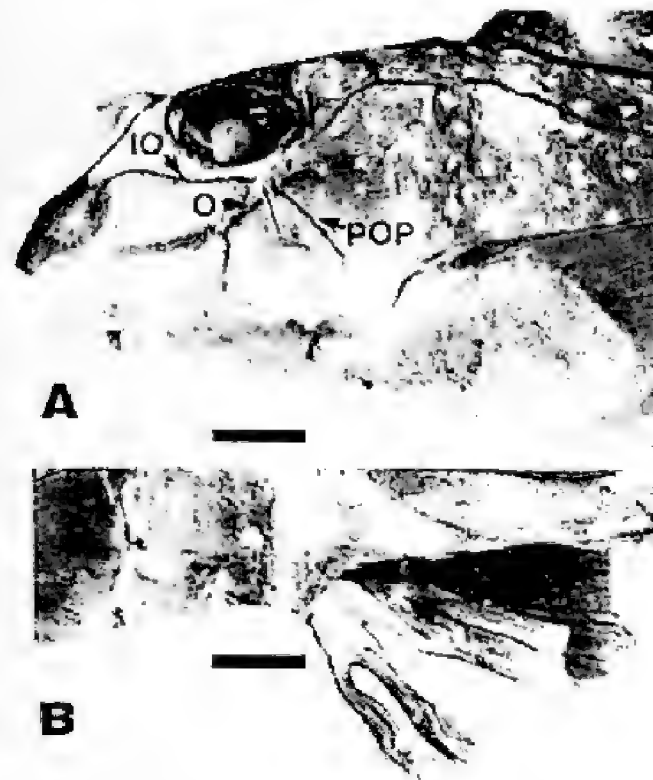


Fig. 3. Characteristics of lateral line canal pattern and pelvic claspers of *Hydrolagus collei* (ANSP 174259). A) lateral view of head; space between oral and preopercular canals indicated by an arrow; IO, infraorbital canal; O, oral canal; POP, preopercular canal; B) pelvic claspers; the left pelvic fin has been cut from the photo and the left pelvic clasper rotated forward and ventrally to reveal the dorsal view. Scale = 2 cm.

Distribution ---From southeastern Alaska to Baja California and the northern Gulf of California, recorded from depths ranging from the surface to 913 m (Hart 1980; Eschmeyer et. al. 1983).

Specimens examined ---59 specimens: ANSP 174259, Alaska, Aug. 1995; ANSP 174260 (2), Alaska, Aug. 1995; MCZ 1451 (2), Pacific Ocean; FMNH 17121, FMNH 17122, FMNH 17123, Pacific Grove, CA; FMNH 10152, FMNH 10154, Seattle, WA; UW 22048 (6), Hood Canal, WA; UW 26184, Westpoint, Puget Sound, WA, 5 fms; UW 26182, Jefferson Head, Puget Sound, WA; UW 4772, Redondo Beach, WA; UW 8559 (2), Ward Cove, Reuilla Is., Alaska; UW 21464, Puget Sound, WA, 4 fms; UW 8566, Indianola, WA; UW 26185, Puget Sound (44°06'N, 124°28'W), 50 m; UW 16045, Puget Sound, WA; UW 29405 (2), Ketchikan, AK; UW 4719 (3), Puget Sound, WA; UW 17145 (2), Meadow Point, Puget Sound, WA; UW 26183, Murden Cove, Puget Sound, WA; UW 19634 (4), Puget Sound, WA; UW 22049, Puget Sound, WA; UW 8564 (3), Inskik Channel; UW 17872 (2), West of McArthur Bank, Strait of Juan de Fuca; UW 17699 (3), Friday Harbor, WA; UW 5826, Thorndike Bay, Hood Canal, WA; UW 21465, Puget Sound, WA; UW 17511, Humboldt Bay, Puget Sound, WA; UW 4693 (3), North Beach, Puget Sound; UW 4214, Mukilteo, Puget Sound, WA, 13 Apr. 1936; UW 26181 (2), Meadow Point, Puget Sound, WA, 100 m; MNHN 1896-99 Pacific Northwest, gift from Smithsonian Institute; MNHN A3288 California, Monterey, gift from Smithsonian Institute; HUMZ 34329 North Pacific (56°03'N, 135°19'W), 338-340 m, 20 Jan. 1970; AMS I.6626 Puget Sound, WA.

DISCUSSION

Despite the fact that *Hydrolagus collieri* is a relatively common species, very little is known about its habits and biology. Studies have shown that they feed on a variety of bottom dwelling invertebrates particularly polychaete worms, mollusks, crustaceans, small fishes, and even other ratfish (Johnson and Horton 1972, Quinn et al. 1980). A few isolated studies provide evidence that ratfishes segregate themselves by both sex and size. In a study of *H. collieri* in Puget Sound it was shown that larger fish tend to move into shallower waters while juveniles tend to aggregate in deeper waters (Quinn et al. 1980) and in a study of *H. collieri* in the Gulf of California it was found that males and females tended to aggregate separately (Mathews 1975). There are no published studies demonstrating these same aggregation patterns off the coast of California; however, based on catch records and personal experience, these trends tend to be common throughout the range and for other species of chimaeras. Insufficient data has been collected on populations in the Gulf of California and the Pacific coast of Baja to determine if the Gulf of California populations are continuous with those in the Pacific and if they migrate between the Gulf from the Pacific Ocean, or if *H. collieri* populations in the Gulf are separate from those in the Pacific. No observable morphological differences have been noted and molecular data may be necessary to determine the relationship between Pacific and Gulf populations of *H. collieri*.

Efforts to age chimaeroids have not met with success. Johnson and Horton (1972) looked at eye-lens weights, vertebral radii, spine sections, and body-length frequencies as possible methods for ageing *Hydrolagus collieri*; none of their methods proved useful for age determination. It was suggested that ridges on the vomerine tooth plates may be useful for ageing *H. collieri* (Johnson and Horton 1972); however, because tooth plates are ever-growing, and are known to change morphology as the fish grows (Garman 1904, Didier et al. 1994), it is unlikely that fish can be aged on the basis of tooth plate morphology. Sullivan (1978) studied the banding pattern in the dorsal fin spine of *Callorhynchus milii*, and based on annual ring deposition estimated that males mature at about 3 years and females at 4.5 years. A more recent study of growth rates of *C. milii* found that growth rates differed among different populations and that growth rates actually increased over time so that males collected in the 1960's matured at 4+ years and males collected in the 1980's matured at 2+ - 3+ years (Francis 1997). Whether or not these same growth trends are typical of *H. collieri* is yet unknown.

All chimaeroids reproduce by internal fertilization and are oviparous. It has long been assumed reproduction in ratfishes occurs in much the same way as in sharks; however, the role of the frontal tenaculum has always puzzled observers of this unique fish and only recently has it been observed that males use the frontal tenaculum to grasp the pectoral fin of the female during copulation (D. Powell, Monterey Bay Aquarium, pers. obs.). The prepelvic tenacula are capable of flexing anteriorly from their pouches and are probably used to aid in anchoring the male to the ventral side of the female as the pelvic claspers flex forward toward the oviducal openings of the females and sperm is transferred directly to the oviducts of the female. This awkward clasping arrangement is possible because males tend to be smaller than females and have a shorter trunk

length. A recent study of *Callorhynchus milii* has shown that females do store sperm (Smith et al.³ 2001), and it is likely that all chimaeroids have this ability. The large yolky eggs are fertilized within the upper end of the oviduct and pass through the shell (or nidamental) gland where the each egg is encapsulated in a tough, leathery egg capsule. One egg will be extruded from each oviduct, with pairs of eggs laid about every 10 – 14 days (K. Wong, Vancouver Aquarium, D. Didier, pers. obs.). Egg capsules of *Hydrolagus coliei* are spindle-shaped with a bulbous portion that contains the single egg within and tapering to a long slender point (Fig. 4). After extrusion egg capsules remain attached to the shell gland within the oviduct for a period of 24-72 hrs. (Dean 1906; D. Didier, pers. obs.) and eventually are deposited on the bottom. Egg capsule shape varies and can be useful for species identification, unfortunately because the egg capsules are generally collected separate from the females that laid them, and are usually empty when collected, it's usually impossible to associate egg capsules with the species. The egg capsules have tiny slits at both ends (Dean 1906; D. Didier, pers.



Fig. 4. Egg capsule and embryo of *Hydrolagus coliei* collected by trawl, San Juan Islands, Puget Sound. The distal tip of the egg capsule was probably damaged some time prior to collection in the trawl as evidenced by the blackened color of the egg capsule and damaged tissue at the tip of the embryo's tail. External gill filaments are visible as a mass of blood-filled capillaries extending from beneath the developing opercular flap, just posterior to the eye. Until the functional gills develop, the external gill filaments provide a large surface area for gas exchange.

³Smith, R.M., R.W. Day, T.I. Walker, and W.C. Hamlett. 2001. Microscopic organization and sperm storage in the oviducal gland of the elephant fish, *Callorhynchus milii*, at different stages of maturity. 6th Indo-Pacific Fish Conference, Scientific programme, abstract.

obs.) and embryos will beat their tails constantly to create a flow of water through the egg capsule for exchange of gases and waste materials. Embryos also rely on the large yolk sac for nutrition during the long developmental period. Based on studies of the development of *Callorhinchus milii* it appears that embryos may take from 6 to nearly 12 months to develop (Didier et al. 1998), but timing is probably highly correlated to water temperature. Embryos are about 13 cm at hatching and resemble miniature adults. Hatchlings are extremely difficult to collect. It may be that the hatchlings aggregate in very deep waters, or in areas that are rarely fished.

Hydrolagus media was described by Garman (1911) and is known only from two syntypes: MCZ-330 (adult male, adult female), 485-541 mm TL, 301-337.5 mm BDL, locality uncertain (Fig. 2B). Garman distinguished *H. media* as distinct from *H. collieri* on the basis of a second dorsal fin completely separated into two parts, as opposed to being only deeply indented in *H. collieri*. In addition, Garman (1911) noted that the coloration of the two species was similar, but more silver in *H. media*, and the eye appeared larger and the body more elongate in *H. media*. The possibility that *H. collieri* and *H. media* were synonymous was first noted by Fowler (1941). Garman's two specimens have been reexamined by the authors and external morphology and body proportions were compared to *H. collieri* to confirm that *H. media* is in fact synonymous with *H. collieri*.

According to Fowler (1910), *Chumaera neglecta* (Ogilbyi 1888) is also synonymous with *H. collieri*. Ogilbyi (1888) identified *C. neglecta* as a new species in his work on the fishes of the Australian museum, but provided no data or description of the specimen, in particular, there is no locality. The next reference to this species name is by Fowler in his description of *Hydrolagus (Chumaera) novaezealandiae* (Fowler 1910) in which he concludes that *C. neglecta* is identical to *H. collieri*. It is quite possible that the species to which Ogilbyi (1888) was referring was in fact the species later named *H. novaezealandiae* by Fowler (1910). There are two reasons for this conclusion. The first is that *H. collieri* is unknown from the southern Pacific Ocean, and since Ogilbyi's work was in reference to fishes in the Australian Museum, and most probably only fishes known primarily from regions around Australia, the specimen was probably not *H. collieri*. Second, the source of confusion between *H. collieri* and *H. novaezealandiae* may lie in the fact that these two distinct species are similar in overall size and body shape, and more importantly they are two of the only species of *Hydrolagus* having a distinct body coloration with numerous white spots on the head, trunk, and tail. If this is indeed the case, *C. neglecta* would be a synonym of *H. novaezealandiae*, rather than *H. collieri*; however, the location of the specimen is unknown, and without accurate locality data, confirmation is impossible. Regardless, the name *C. neglecta* is preoccupied by a fossil species and thus would not have precedence over the name *H. novaezealandiae* (Fowler 1910).

Body measurements and proportions for *Hydrolagus collieri* and *H. media* are shown in Table 1. Data collected from a sample of 59 specimens of *H. collieri* indicate that females tend to be larger than males, although there is no clear size separation between males and females. For almost every measurement taken the specimens of *H. media* fall within the observed ranges for *H. collieri*. Three measurements of *H. media*

Table 1. Range of measurements and proportions of body length (%BDL) for *Hydrolagus colliciei* and *Hydrolagus media*

	<i>Hydrolagus colliciei</i> (n=21) males		<i>Hydrolagus colliciei</i> (n=38) females		<i>Hydrolagus media</i> male		<i>Hydrolagus media</i> female	
	<u>mm</u>	<u>range %BDL</u>	<u>mm</u>	<u>range %BDL</u>	<u>mm</u>	<u>%BDL</u>	<u>mm</u>	<u>%BDL</u>
TL	123-515	143-217	176-583	139-225	485	161	541	160
PCL	78.3-386	123-142	114-457	127-147	391	130	417.5	124
BDL	59.5-313	100	80-359	100	301	100	337.5	100
SVL	40-227	67-88	69-275	71-93	215	71	223.5	66
TRL	22.9-139	38-50	37-180	39-55	141	47	157	47
PD2	68-215	65-79	46-253	40-88	205.5	68	224	66
PD1	23.1-115	33-49	24-138	21-53	110.5	37	118.5	35
POB	6.7-49	11-21	18-65	13-23	41.2	14	36.3	11
D2B	37.2-190	58-69	52-217	57-72	181.5	60	195.5	58
D2AH	8.0-18	5-8	7.0-23	5-10	10.3	3	16.8	5
D2PH	6.0-14	3-6	2.0-16	1-7	6.8	2	11.5	3
D1B	11.8-57.9	16-24	16-72.4	15-26	51.5	17	86.4	26
DSA	15.8-83	22-30	19-100	22-31	75	25	99	29
D1H	12.3-77.3	19-27	24-89.4	17-30	59.3	20	75.7	22
CDM	23.5-115	29-59	4-142	24-68	105.4	35	120.6	36
CDH	5.0-11	2-5	3-15	2-6	5.8	2	7.0	2
CVM	25.3-137	37-72	56-152	26-91	113	38	122.8	36
CVH	4.0-10	2-5	3-14	2-5	5.7	2	6.4	2
HDL	17.8-96	26-43	35-125	27-45	84.8	28	84.4	25
P1A	22.2-114	32-43	36-130	31-46	95.7	32	120.3	36
P2A	22-80	20-31	18-74	18-25	68.5	23	65.2	19
IDS	5.5-52.7	9-20	11-71.6	09-21	49.2	16	28.4	8
DCS	1.0-6.7	1-2	1.0-6.8	01-03	4.9	2	3.1	1
D1P1	12.1-82	20-34	22-105	20-34	59.3	20	67	20
D1P2	23.3-140	39-50	35-165	40-52	117.7	39	136	40
D2P1	23.4-137	38-48	32-162	37-53	119.7	40	133	39
D2P2	9.9-60	17-26	17-80	17-27	46	15	50	15
EYL	7.2-30	8-15	10-29	7-16	29.2	10	29.2	9
EYH	5.0-21	6-10	7.0-21	5-10	17.7	6	19.8	6
CLT	1.8-60	3-24			53.3	18		

exceeded the range observed in *H. colliciei* (PCL and TRL for the male, and D1B in the female), but still fell within the observed proportion of body length. For some measurements (SVL, D2AH, HDL, IDS, and D2P2) the percent body length in *H. media* was 1-2% lower than that observed for *H. colliciei*. These differences can be attributed to sampling error as *H. media* was represented by only two adult specimens, or measurement error as a result of shrinkage or stretching of specimens. It is also possible that the color differences noted by Garman (1911) are indicative of geographic variation;

however, subtle differences in color are difficult to evaluate, particularly in preserved specimens. Examination of large numbers of fresh specimens throughout the known range of the species will be needed to fully understand the patterns of color and geographic variation. In particular, a closer examination of specimens from California may be helpful in understanding biology of this species throughout its range.

Hydrolagus coliei and *H. media* share the same combination of external features including coloration, lateral line canal pattern, secondary sexual characteristics, and fin shapes. The coloration and pattern of the white spots along the body is the most obvious unique feature that they share. Subtle differences in the silvery coloration could not be evaluated due to specimens stored in alcohol for many years. *Hydrolagus coliei* and *H. media* also share a characteristic second dorsal fin in which a dip in the middle almost separates the fin into two parts. In a large sample of *H. coliei* we found that the depth of the second dorsal fin indentation was highly variable and therefore not a useful feature for characterizing the species. The *H. media* syntypes exhibit the same sexual dimorphism in shape of the pelvic fin as was observed in *H. coliei*. Sexual dimorphism in pelvic fin shape is unusual among chimaeroids and has so far been observed in only one other species, *H. novaezealandiae* (L. Rosenberger and D. Didier, pers. obs.). There is no obvious difference in the morphology of the dorsal fin spine or its height relative to the height of first dorsal fin in adults. The lateral line canal patterns are the same in every respect, in particular the presence of a small space separating the oral and preopercular canals at their origin from the infraorbital canal. The claspers of both *H. coliei* and *H. media* are bifid, divided for 2/3 their length, and widely separated at the bifurcation. Garman's reference to trifid claspers in the original description of *H. media* is apparently an error. The pre-pelvic tenacula, frontal tenacula, and pelvic claspers are the same shape in both as well. Based on our observations *H. coliei* and *H. media* cannot be distinguished by any morphological difference and our observations support Fowler's conclusion that *H. media* is a subjective synonym of *H. coliei*.

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STRUCTURE, SAMPLING GEAR AND ENVIRONMENTAL ASSOCIATIONS, AND HISTORICAL CHANGES IN THE FISH ASSEMBLAGE OF THE SOUTHERN SACRAMENTO-SAN JOAQUIN DELTA

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We sampled fishes at 11 fixed sites monthly from January 1993 through December 1994 in the southern Sacramento-San Joaquin Delta. Using three different sampling gears (boat electrofishing, gillnets, and hoopnets), we obtained 988 samples and collected 27,791 fishes representing 33 species. Overall, the catch was heavily dominated by alien species which represented 99% of the total number of fishes we collected. We used partial canonical correspondence analysis (pCCA) to examine the effect of gear type and environmental variables on fish assemblage structure. Gear type strongly influenced the observed assemblage structure accounting for 59% of the variation explained by pCCA. Ictalurids dominated the hoopnet catches. Ictalurids, striped bass, *Morone saxatilis*, and splittail, *Pogonichthys macrolepidotus*, dominated the gillnet catches, while centrarchids dominated the electrofishing catches. Electrofishing collected approximately 50% more species than the other two gear types, suggesting that it may be the most favorable of the three to assess presence-absence, although it apparently did not sample large mobile fishes very well. After accounting for the effect of gear type, flow and water temperature had the strongest influence on assemblage structure. The south Delta fish assemblage has changed greatly since it was first described 30 years prior to our study. Two native species have apparently been extirpated and at least eight alien species have established reproducing populations. Our results (1) suggest that, depending upon the goals of the study, the use of a single sampling gear may provide a biased assessment of the south Delta fish assemblage and (2) corroborate the hypothesis that highly altered habitats are vulnerable to the invasion and establishment of alien species.

INTRODUCTION

Fish assemblages are increasingly being used as indicators of perturbation in aquatic ecosystems in California's Central Valley (Brown and Moyle 1993, Brown 2000, Moyle 2002, May and Brown 2002). The findings of recent studies suggest that water management practices have significant effects on fish assemblages in that highly disturbed habitats typically are dominated by alien species (Saiki 1984, Brown 2000, Saiki et al. 2001, May and Brown 2002). The point of drainage for California's Central Valley is the Sacramento-San Joaquin Delta (Delta), a highly altered system (Nichols et al. 1986).

The Delta consists of over 1,000 km of waterways with a drainage area encompassing approximately 40% of California's surface area (Nichols et al. 1986). In any given year, up to 65% ($73 \times 10^8 \text{ m}^3$) of the Delta's natural discharge is diverted for agricultural and municipal consumption at large pumping facilities in the south Delta by the State Water Project and Central Valley Project (Nichols et al. 1986). Due to degraded physical habitat, hydrodynamics, and water quality associated with water diversion facilities and flood control projects, the south Delta is arguably the most degraded region of the San Francisco Estuary (Arthur et al. 1996).

The purpose of this paper is to provide a comprehensive assessment of the structure of the south Delta fish assemblage by examining fish monitoring data that incorporated three different sampling gears. By incorporating data from three different gear types in our analyses, we expanded upon the community analysis conducted by Feyrer and Healey (2003) who relied solely on electrofishing data. Further, we employed multivariate statistical techniques to examine the effect of gear type on fish catches, and while accounting for the effect of gear type, examine how species abundances related to environmental variables. We also compared our results of species occurrences to that of Turner and Kelley (1966) to provide a general assessment of how the south Delta fish assemblage has changed 30 years after it was first described.

STUDY SITE

We sampled fishes at 11 sites in the south Delta: 3 sites each in Old River, Middle River, Grant Line Canal, and 2 sites in the San Joaquin River (Figure 1). These waterways, referred to locally as sloughs, are approximately 1 to 5 meters in depth, tidally influenced, and are constricted within flood control levees. Rock-reinforced banks (riprap) dominate riparian habitats and non-native submerged aquatic vegetation, primarily the Brazilian waterweed, *Egeria densa*, is prevalent in the littoral zone. The primary source of freshwater for the south Delta is the San Joaquin River. Agriculture is the dominant land use activity beyond the channel levees and hundreds of small local agricultural diversion facilities are scattered within the region.

METHODS

Each site was sampled for fishes at least once per month with each gear type from

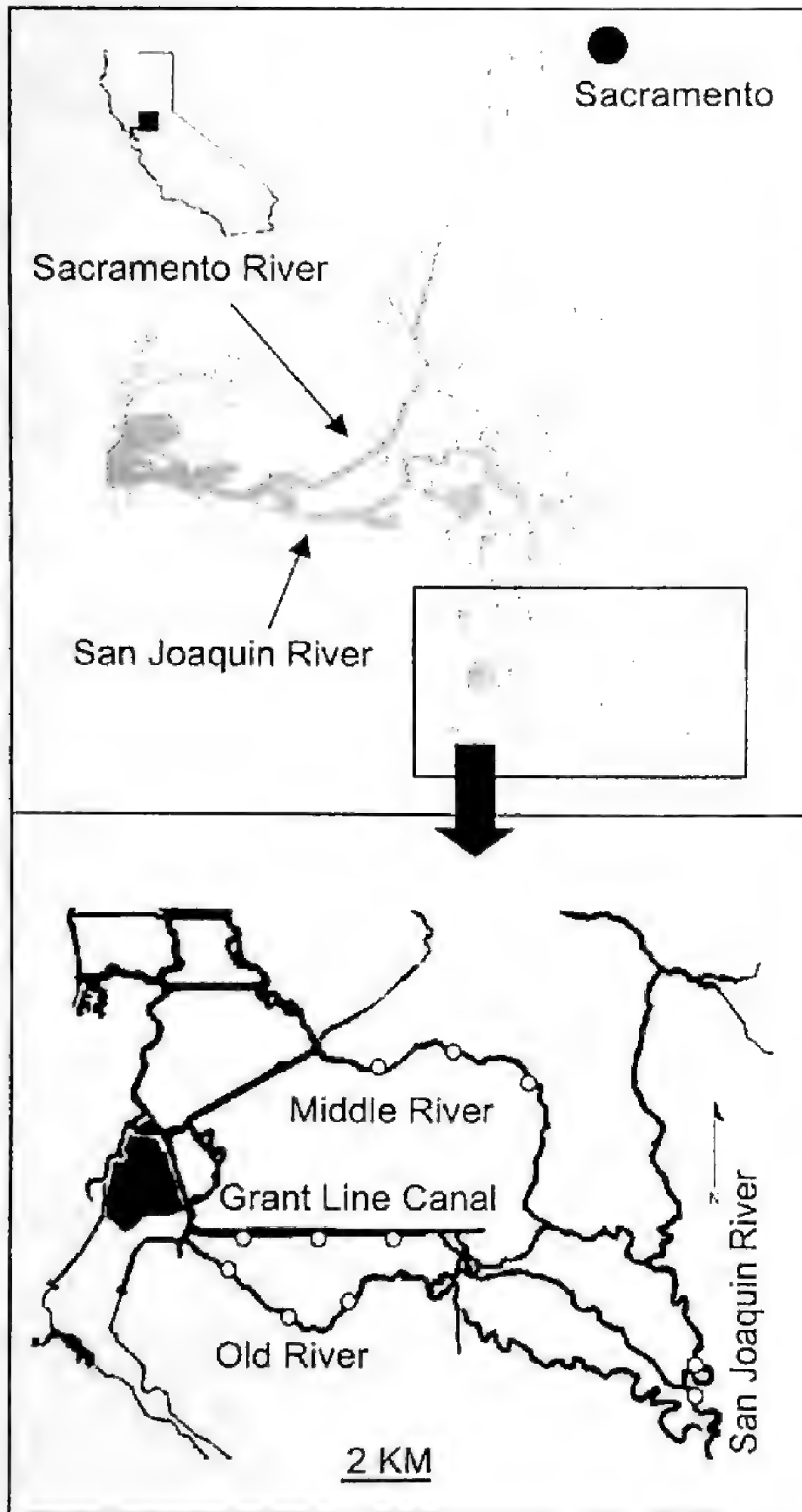


Figure 1. Fish sampling sites (open circles) in the southern Sacramento-San Joaquin Delta.

January 1993 through December 1994; 988 total samples were obtained (Table 1). To minimize potential temporal biases in the sampling, the three gear types were usually used within the same calendar week. Each sampling gear was used at each site as follows. Boat-employed pulsed AC electrofishing was conducted after dark at fixed transects set along one bank at each site. The transects were approximately 500 m in length, and to the extent possible, equal effort (shock time) was made each time an individual transect was sampled. All fishes that were collected were retained alive in tubs of water on the sampling boat until a transect was completed. Thereafter, fishes were identified to species and released. Hoopnet sampling was conducted on banks opposite or adjacent to the electrofishing transects. Two hoopnets, each measuring 5 m in length with 25 mm-stretch-mesh netting and 1-m diameter hoops, were set in-line, approximately 50-100 m apart, and parallel to the shoreline. The hoopnets were set during the day at depths ranging from 3-5 m and retrieved after 40-48 hr. Gillnet sampling was also conducted on banks opposite or adjacent to the electrofishing transects. Two monofilament gillnets, each measuring 50 m in length and 4 m in depth with 50 to 100-mm variable mesh, were set in the late afternoon and into the evening. The two gillnets were fished simultaneously in hour-long sets with one oriented parallel to shore and the other oriented perpendicular to shore. The two gillnets were normally set approximately 10-50 m apart from each other. At least two gillnet sets (two nets per set) were normally completed during each outing. As with the electrofishing, all fishes collected by hoopnet and gillnet were identified to species and released. Water temperature ($^{\circ}\text{C}$), specific conductance (μS), and turbidity (NTU), were measured when fish samples were obtained and tidally averaged daily flow ($\text{m}^3 \text{s}^{-1}$) for each location was obtained from the California Department of Water Resources CALSIM hydrology model.

Table 1. Total number of samples by month for the period January 1993 through December 1994 in the southern Sacramento-San Joaquin Delta. E = electrofishing, G = gillnet, H = hoopnet.

Month	1993			1994		
	<u>E</u>	<u>G</u>	<u>H</u>	<u>E</u>	<u>G</u>	<u>H</u>
January	15	12	15	14	16	15
February	15	13	15	14	10	15
March	14	14	15	15	7	10
April	13	17	15	14	15	15
May	15	12	15	15	18	13
June	15	14	15	15	12	15
July	15	17	15	15	13	15
August	14	15	15	15	7	11
September	15	12	11	15	8	12
October	15	9	19	15	9	15
November	9	9	15	15	14	15
December	15	8	15	15	14	15

We used canonical correspondence analyses (CCA) to examine the effect of gear type and environmental variables on species abundances. CCA is a multivariate direct ordination technique that extracts synthetic environmental gradients that maximize niche separation within assemblages, thereby facilitating the interpretation of how species abundances relate to environmental variables (ter Braak and Verdonschot 1995). The CCAs were run with the CANOCO software program (ter Braak & Smilauer 1998) with untransformed environmental and fish relative abundance data. To reduce the influence of rare species and therefore minimize the possibility of misleading interpretations of the resulting ordination diagrams, we only included species that occurred in at least 5% of the samples for each gear type (Table 2). We conducted an

Table 2. Species, total number, and percent number (if $\geq 1\%$) of fishes captured by electrofishing, gillnet, and hoopnet sampling, January 1993 through December 1994 in the southern Sacramento-San Joaquin Delta. Species are listed in order of overall abundance. Asterisk indicates native species.

<u>Species</u>	<u>Electrofishing</u> <u>No.</u>	<u>Gillnet</u> <u>No.</u>	<u>Hoopnet</u> <u>No.</u>	<u>Totals</u> <u>No.</u>	<u>%No.</u>
White catfish <i>Ameiurus catus</i>	2,271 ¹	864 ¹	7,316 ¹	10,451	38
Bluegill sunfish <i>Lepomis macrochirus</i>	5,757 ¹	80 ¹	348 ¹	6,185	22
Redear sunfish <i>Lepomis microlophus</i>	2,902 ¹	102 ¹	183 ¹	3,187	12
Largemouth bass <i>Micropterus salmoides</i>	2,030 ¹	100 ¹	5	2,135	8
Golden shiner <i>Notemigonus crysoleucas</i>	1,162 ¹	26 ¹	3	1,191	4
Channel catfish <i>Ictalurus punctatus</i>	119 ¹	90 ¹	808 ¹	1,017	4
Striped bass <i>Morone saxatilis</i>	607 ¹	255 ¹	42 ¹	904	3
Inland silverside <i>Menidia beryllina</i>	635 ¹	0	0	635	2
Threadfin shad <i>Dorosoma petenense</i>	459 ¹	1	0	403	2
Brown bullhead <i>Ameiurus nebulosus</i>	67 ¹	14	322 ¹	403	2
Common carp <i>Cyprinus carpio</i>	203 ¹	33 ¹	141 ¹	377	1

Goldfish <i>Carassius auratus</i>	120 ¹	4	5	129	1
Warmouth <i>Lepomis gulosus</i>	90 ¹	1	1	92	
Splittail* <i>Pogonichthys macrolepidotus</i>	5	74 ¹	3	82	
Tule perch* <i>Hysterocarpus traski</i>	67 ¹	2	12	81	
Smallmouth bass <i>Micropterus dolomieu</i>	59 ¹	2	0	61	
Sacramento sucker* <i>Catostomus occidentalis</i>	49 ¹	6	1	57	
Black bullhead <i>Ameiurus melas</i>	22	3	30 ¹	55	
Black crappie <i>Pomoxis nigromaculatus</i>	29 ¹	6	17	52	
Yellowfin goby <i>Acanthogobius flavimanus</i>	50 ¹	0	0	50	
Green sunfish <i>Lepomis cyanellus</i>	35 ¹	0	0	35	
Shimofuri goby <i>Tridentiger bifasciatus</i>	34 ¹	0	0	34	
Chinook salmon* <i>Oncorhynchus tshawytscha</i>	24	6	0	30	
American shad <i>Alosa sapidissima</i>	20	5	1	26	
Mosquitofish <i>Gambusia affinis</i>	19	0	0	19	
Bigscale logperch <i>Percina macrolepidota</i>	12	0	0	12	
Sacramento blackfish* <i>Orthodon microlepidotus</i>	6	6	0	12	
White crappie <i>Pomoxis annularis</i>	0	0	7	7	
Sacramento pikeminnow* <i>Ptychocheilus grandis</i>	5	1	0	6	
Prickly sculpin* <i>Cottus asper</i>	2	0	0	2	

Yellow bullhead <i>Ameiurus natalis</i>	0	1	1	2
Steelhead* <i>Oncorhynchus mykiss</i>	1	0	0	1
White sturgeon* <i>Acipenser transmontanus</i>	0	0	1	1
Total species	30	23	20	33
Total no.	16,861	1,683	9,247	27,791

*Included in statistical analyses - occurred in at least 5% of the samples for the specified sampling gear.

initial CCA that included each of the environmental variables (gear type, month, year, site, flow, temperature, specific conductance, and turbidity) and discovered that gear type had the greatest overall influence on the observed assemblage structure. Therefore, we then conducted partial CCAs (pCCA) to partition the amount of variance (inertia) associated with gear type and the other remaining variables (Økland and Eilertsen 1994). Two pCCAs were run: the first was run with gear type as a covariable and the remaining variables as the environmental variables and the second was run with gear type as an environmental variable and the remainder as covariables. This allowed us to factor out the amount of variance explained by gear type alone, the amount of variance explained by the other environmental variables separate from gear type, and also the amount of variance jointly explained by these two groups. For all models, sampling gear, site, and month were coded as categorical variables as follows: electrofishing = 1, gillnet = 2, hoopnet = 3, San Joaquin River = 1, Middle River = 2, Old River = 3, Grant Line Canal = 4, January = 1, February = 2, etc. We used the forward selection procedure with Monte Carlo simulations (199 permutations) provided by CANOCO to constrain each of the models to only include environmental variables significant at $p < 0.05$ (ter Braak & Smilauer 1998).

RESULTS

Our sampling effort captured 27,791 fishes, primarily age-1 and above, representing 33 species (Table 2). The catch was dominated by alien species, especially by centrarchids and ictalurids, which comprised 73% of the species and 99% of the individuals collected. The most abundant native resident species were splittail, *Pogonichthys macrolepidotus*, tule perch, *Hysterocarpus traski*, and Sacramento sucker, *Catostomus occidentalis*, each of which, however, represented less than 1% of the total individuals collected (Table 1).

Results of the pCCAs indicated that gear type had the greatest influence on fish

abundances, accounting for 59.1% (sum of canonical eigenvalues = 0.312) of the variance explained by CCA. The biplot of the full CCA model incorporating all variables (Figure 2) demonstrated how individual species tended to be collected with certain gear types. Ictalurids and common carp, *Cyprinus carpio*, were highly associated with the hoopnet samples, while splittail and striped bass, *Morone saxatilis*, were associated with the gillnet samples, and the remaining species were mostly associated with the electrofishing samples. Variables other than sampling gear combined to account for 40.5% (sum of canonical eigenvalues = 0.214) of the variance explained by CCA. Because only 0.4% of the explained variance overlapped between the two groups (sum of canonical eigenvalues = 0.002), the pCCA with gear type as a covariable was effective

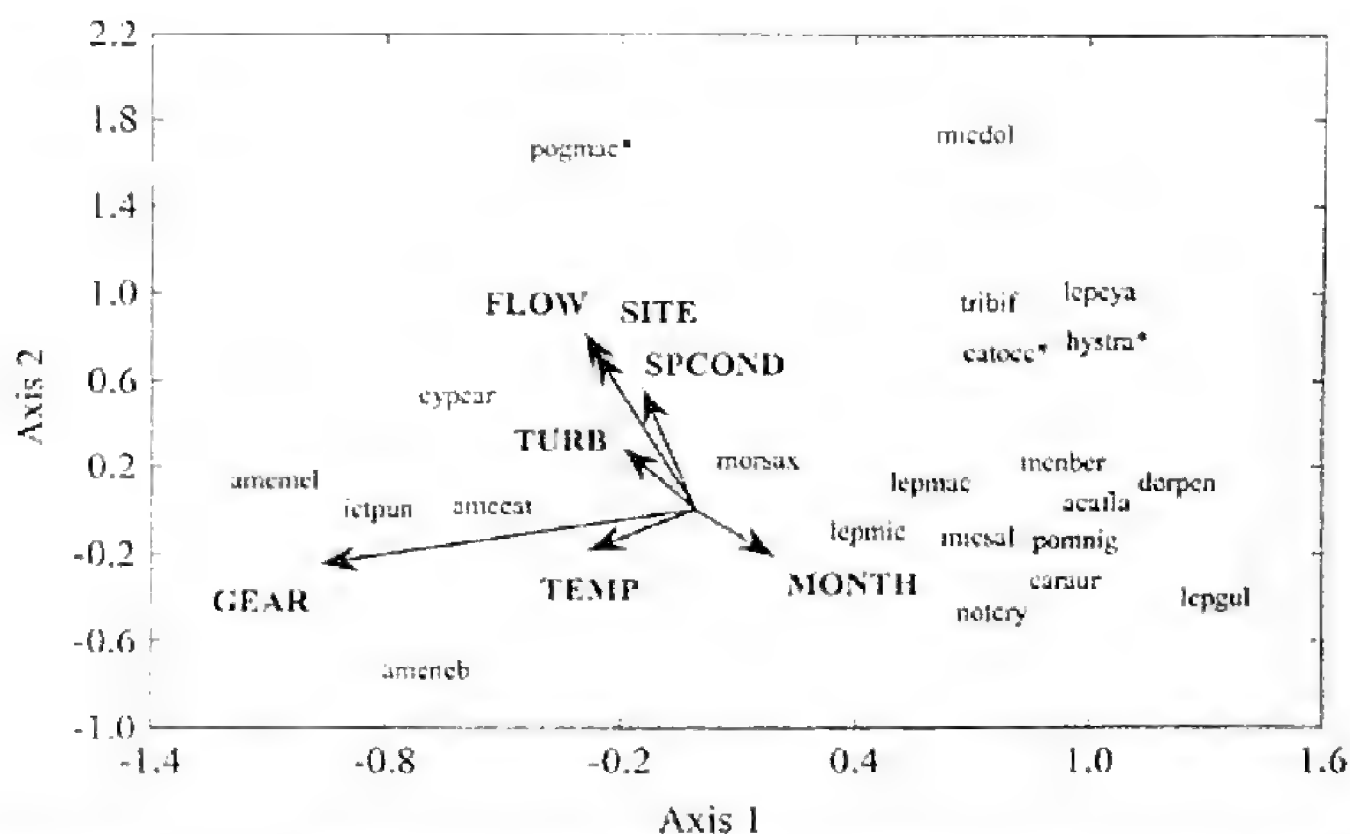


Figure 2. Biplot of the full canonical correspondence analysis model incorporating gear type. Species codes represent the first three letters of the genus and species. Asterisks indicate native species. SPCOND = specific conductance, TURB = turbidity, TEMP = temperature.

at describing how fish abundances related to environmental variables while accounting for the influence of gear type (Table 3). The biplot of this pCCA (Figure 3) demonstrated that species were distributed primarily along an environmental gradient of river flow. The most notable observation was that the native species (splittail, tule perch, and Sacramento sucker), were associated with high river flow relative to the other species. Smallmouth bass, *Micropterus dolomieu*, green sunfish, *Lepomis cyanellus*, and shufro goby, *Tridentiger bifasciatus*, exhibited similar environmental associations. The majority of the remaining species were associated with either low or moderate river flow. These species then differentially clustered primarily along an environmental gradient of water temperature (Figure 3). Striped bass and channel catfish, *Ictalurus*

Table 3. Summary statistics of the partial canonical correspondance analysis run with fish relative abundance and environmental variable data with sampling gear as a covariable. Total inertia = 5.23.

Variable	Axis 1	Axis 2
Eigenvalue	0.11	0.06
Species-environment correlation	0.48	0.36
Cumulative percentage of variation		
Explained by species only	2.2	3.4
Explained by species and env. variables	50.3	77.7
Inter-set correlations with axes		
Flow	0.35	0.16
Site	0.33	0.12
Temperature	0.19	-0.32
Specific conductance	0.19	0.17
Turbidity	0.19	0.02
Month	-0.12	-0.07

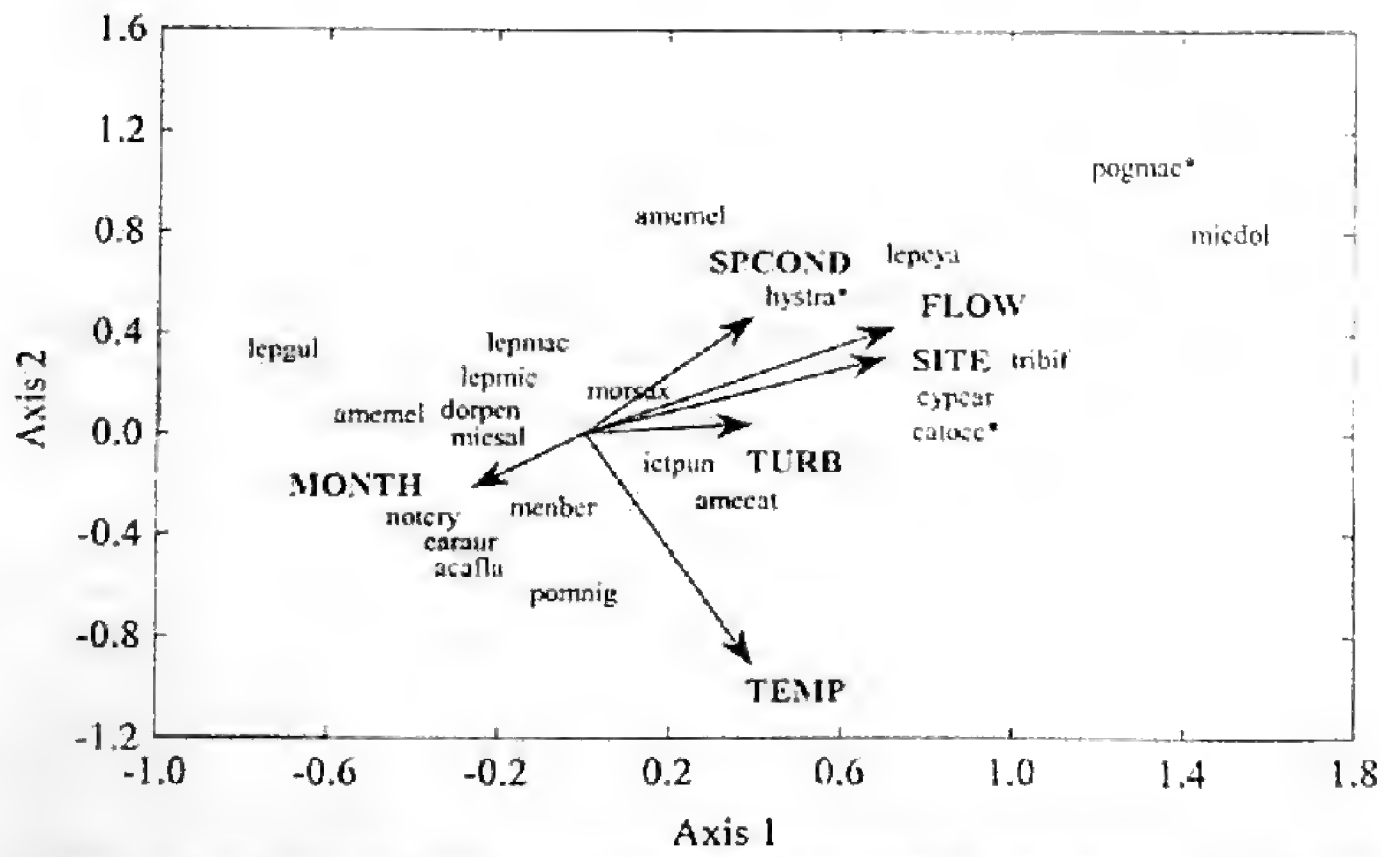


Figure 3. Biplot of the partial canonical correspondence analysis demonstrating the environmental associations of species while accounting for the effect of the three different gear types as a covariable. Species codes represent the first three letters of the genus and species. Asterisks indicate native species. SPCOND = specific conductance, TURB = turbidity, TEMP = temperature.

punctatus, had scores near the origin (Figure 3), indicating that they were relatively evenly distributed in the south Delta in space and time during the sampling period.

DISCUSSION

The south Delta fish assemblage is dominated in numbers by alien species and abundances are structured primarily along environmental gradients of river flow and water temperature. Although native fishes were collected at all locations, they represented only 27% of the species and 1% of the total number of fishes collected over the course of the study. Utilizing electrofishing data, Feyrer and Healey (2003) found that native species remained uncommon in the south Delta through 1999. Our observations of the environmental associations of native and alien species are consistent with those from other studies conducted in the Sacramento-San Joaquin Delta and adjacent areas (Brown 2000, May and Brown 2001, Matern et al. 2002, Feyrer and Healey 2003).

Sampling gear strongly influenced the observed fish assemblage structure, accounting for 59.1% of the variation explained by CCA. We found that hoopnet catches were highly dominated by ictalurids. Pugh and Schramm (1998) evaluated electrofishing and hoopnetting in the lower Mississippi River and similarly found that hoopnet samples were generally dominated by ictalurids. Gillnets were also effective at collecting ictalurids, as well as mobile fishes such as striped bass and splittail. Although electrofishing did not appear to be very effective at collecting the large mobile fishes, it did appear to provide the best overall assessment of species presence-absence as it collected approximately 50% more species than the other two gear types.

Differences in assemblage structure are a common result when incorporating different gear types (Allen 1982, Weaver et al. 1993, Fago 1998, Onorato et al. 1998) and can be attributed to many interacting factors. These include the ability of certain species to avoid or escape certain gears due to morphological and behavioral characteristics, and that the differing sampling gears are not equally effective in all habitats. For example, although each gear sampled the same general sites, they had to be deployed in slightly different microhabitats. Gillnets and hoopnets were used in open water areas generally at least 3 meters in depth. The nets could be set near potential fish cover such as downed trees or submerged aquatic vegetation but could not be set directly in such cover because the nets would foul. Electrofishing, on the other hand, could be conducted in shallow water directly within such cover. Thus, the differences in fish assemblage structure among the gear types are functions of both species-specific avoidance capabilities as well as microhabitat preferences of the fishes. Additionally, different sizes, forms, or deployment methods of the gear types we used could potentially exhibit different catch characteristics. Jackson and Bauer (2000) and Pine (2000) demonstrated that gears of smaller mesh were generally more effective at collecting smaller sized centrarchids than identical gears of larger mesh. Our observations of the strong sampling gear associations of certain species suggest that multiple sampling gears are required to provide a comprehensive inventory of fishes in the south Delta.

There have been notable changes to the south Delta Fish assemblage over the 30 years since it was first described by Turner and Kelly (1966). These changes include the apparent extirpation of two native species and the introduction and establishment of at least eight alien species. Turner and Kelley (1966) utilized gillnets, otter trawls, and midwater trawls to sample fishes in Grant Line Canal (called Fabian Canal by Turner and Kelley) and the San Joaquin River monthly from 1963 through 1964. Although there may be some bias attributable to gear selection and methodology, the intensity and duration of sampling by the two studies provides an opportunity to assess the general changes in the fish assemblage over the course of this 30-year time span. Native fishes collected in the south Delta by Turner and Kelley (1966) which were absent from our samples include hitch, *Lavinia exilicauda*, starry flounder, *Platyichthys stellatus*, and delta smelt, *Hypomesus transpacificus*. Delta smelt were not collected during our study because our sampling gear was unsuitable for capturing this small midwater species. However, sampling gear bias most likely did not contribute to the absence of hitch and starry flounder in our samples because gillnets and electrofishing have collected these species in other regions of the Delta (Baxter 1996¹, Michniuk and Silver 2002²). In terms of alien fishes, the shimofuri goby, *Tridentiger bifasciatus* (Matern and Fleming 1995), yellowfin goby, *Acanthogobius flavimanus* (Brittan et al. 1970), bigscale logperch, *Percina macrolepidota* (Moyle et al. 1974), inland silverside, *Menidia beryllina*, (Moyle et al. 1974), redear sunfish, *Lepomis microlophus*, and smallmouth bass, *Micropterus dolomieu*, have all been introduced and have established reproducing populations since Turner and Kelley (1966). Additional likely introductions since Turner and Kelley (1966), based upon the observations of Feyrer and Healey (2003), include the fathead minnow, *Pimephales promelas* (Dill and Cordone 1997), and the red shiner, *Cyprinella lutrensis* (Jennings and Saiki 1990). Feyrer and Healey (2003) also observed western mosquitofish, *Gambusia affinis*, whereas Turner and Kelley (1966) did not. However, this was likely due to Turner and Kelley's (1966) sampling protocol as this species probably invaded the Delta long before their study (Dill and Cordone 1997). Turner and Kelley (1966) did not observe yellow bullhead, *Ameiurus natalis*, in the Delta during their study as we did, however the timing of this introduction is uncertain and may have occurred prior to Turner and Kelley (1966) (Dill and Cordone 1997). Most of these alien species introductions are related to intentional or unintentional stockings of sport or baitfish into the Delta or adjacent systems (Dill and Cordone 1997, Moyle 2002). Due to the significant habitat alterations which have occurred in the south Delta since Turner and Kelley (1966), our results provide support for the hypothesis that highly altered habitats are vulnerable to the invasion and establishment of alien species (Moyle 1986, Ross 1991).

¹ Baxter, R. 1996. Distribution and relative abundance of splittail (*Pogonichthys macrolepidotus*) in the Sacramento and San Joaquin Rivers and Delta during August 1994, with notes on numerous other species collected. Working paper submitted to the Resident Fishes Project Workteam of the Interagency Ecological Program for the San Francisco Estuary.

² Michniuk, D. and G. Silver. 2002. Resident Fish Surveys. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Newsletter 15:2:25-27.

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THE PACIFIC GOLDEN-EYED TILEFISH, *CAULOLATILUS AFFINIS* GILL (TELEOSTEI:MALACANTHIDAE), FIRST OCCURRENCE IN CALIFORNIA

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The family Malacanthidae (tilefishes) has a worldwide marine distribution in tropical and temperate waters and comprises 5 genera and approximately 40 species (Nelson 1994). Two of the four eastern Pacific species are known from California: *Caulolatilus hubbsi* Dooley and *C. princeps* (Jenyns) (Dooley 1978). The status of *C. hubbsi* has been questioned (e.g., Grove and Lavenberg 1997), but other recent authors have maintained its validity (e.g., Allen and Robertson 1994; Moser 1996; Thomson, et al. 2000).

On 3 December 2000, several individuals of a "different" tilefish species were captured by Capt. Dong Reed and others aboard the M/V NEW SEAFORTH off Point Loma, San Diego County (ca. 32°41.0'N, 117°14.0'W), at a depth of 64 m. First-hand accounts indicated that these tilefish were captured with, and thus probably associated with, groups of *Caulolatilus princeps*, the ocean whitefish, a relatively common species in southern California (Miller and Lea 1972). One specimen was secured by one of us (RHS) and brought to the Marine Vertebrates Collection of Scripps Institution of Oceanography where it was identified as *C. affinis*, the Pacific golden-eyed tilefish. It is now accessioned at Scripps, SIO 00-160, 231 mm SL (Fig. 1). Additional specimens, totalling well over 100, were reportedly caught on subsequent fishing trips in the area at least through February 2001.

The anglers catching the "different" tilefish could easily distinguish them from the ocean whitefish by the broad yellow stripe from under the eye to near the end of the snout and by the dark spot above the pectoral-fin axil. *Caulolatilus affinis* is the only eastern Pacific species of tilefish with these two characters and also the only one with

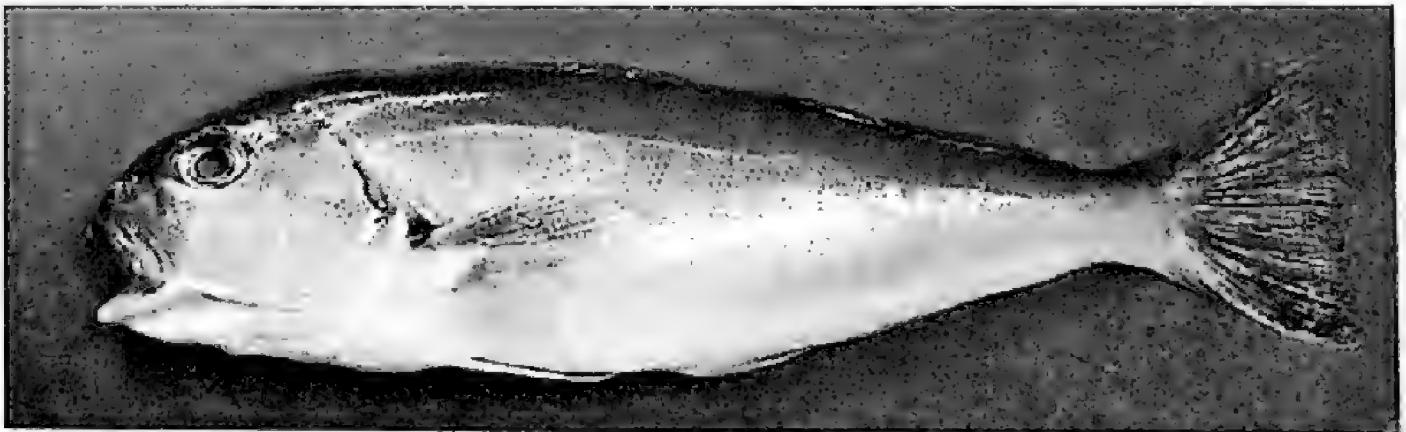


Figure 1. The Pacific golden-eyed tilefish, *Caulolatilus affinis*, 231 mm SL, SIO 00-160.

eight dorsal-fin spines. The only other *Caulolatilus* species with these three characters is the Atlantic species, *C. chrysops* (Valenciennes), which can be distinguished from *C. affinis* by gill-raker count (Dooley 1978). The following counts from our specimen agree well with the counts for *C. affinis* given by Dooley (1978): D, VIII, 24; A, II, 23; P1, 18, 18; total gill rakers 22.

The previously reported range of *C. affinis* is the northern Gulf of California, including Cabo San Lucas, Baja California Sur, and through much of the tropical eastern Pacific to Peru and the Galápagos Islands (Dooley 1978). The occurrence of this tilefish off San Diego thus represents a range extension of over 1300 km from Cabo San Lucas. However, we also report a single individual of this species from Guadalupe Island, off Baja California (ca. 29°10'N, 118°16.0'W), collected in May 1982, depth approximately 55 fms (SIO 84-241). Unfortunately, we only have the head of this specimen, but it is noticeably larger than that of the California specimen.

In tropical waters where this tilefish usually is found, it inhabits moderate depths over rubble and sandy bottoms (Thomson et al. 2000). The sightings and collections of tropical eastern Pacific (Panamic) fishes in California during and after warm-water periods are well documented (e.g., Lea and Rosenblatt 2000; Pondella and Allen 2001). We speculate that the arrival of the Pacific golden-eyed tilefish in California might have been associated with the 1997-1998 El Niño event. Examination of the sagittal otoliths of the California specimen revealed six rings or annuli. Although there are a number of reasons for otolith increment interruptions or transitions in fishes (Bell 2001), a single, annual-ring deposition apparently has been validated for *C. affinis* in the Gulf of California by Elorduy-Garay and Diaz-Urbe (1994). If these annuli do in fact represent yearly growth increments, this fish was approximately 6 years old. This free-swimming, competent juvenile/adult (and the others) simply could have dispersed northward, associated with the warm water mass (Lea and Rosenblatt 2000), not being noticed by California anglers or scientists until it (they) attained a suitable size. Although the size of our specimen is considerably smaller than the mean back-calculated, standard length at age 6 (231 vs. 289 mm) of Elorduy-Garay and Diaz-Urbe (1994), the difference possibly is due to the colder water experience of the California specimen. In addition, we note that the Guadalupe Island specimen also was collected during a period of warm water in the northeastern Pacific (1982-1984).

We hypothesize that other Panamic species could have survived the 1999 La Niña (cool oceanographic condition) and might yet be found in California. In fact, a recent personal communication from Dr. Robert N. Lea, California Dept. of Fish and Game (Feb 2002), alerted us to the collection of *Lutjanus novemfasciatus* Gill, the Pacific dog snapper, in Morro Bay during January 2001.

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We wish to thank Capt. D. Reed and the crew of the M/V NEW SEAFORTH for bringing this fish to our attention. W. Watson kindly reviewed the manuscript. We dedicate this paper to D. Steele, the wife of an enthusiastic professional fisherman, who

has endured for over 30 years the occasional long periods of separation and the never ending fish stories.

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ECONOMICAL TRIPOD RIFLE MOUNT

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The California ground squirrel, *Spermophilus beecheyi*, is considered to be the most serious rangeland vertebrate pest in California because of its forage competition with livestock, ranking it along with pocket gophers, *Thomomys* spp., as a major pest of crops (Marsh 1994). *S. beecheyi* populations also serve as a major public health issue (Barnes 1978). Thus, California ground squirrels are frequently removed because of their impacts to agriculture, or the potential to transmit zoonotic diseases. Removal or collection of these sciurids is frequently undertaken with appropriate firearms. However, it is very difficult to get close (under 50 m) to these animals and they are frequently fired upon from 80 m. This level of difficulty is further compounded since one must often remain standing because of low-lying shrubs and grasses that would otherwise conceal the animal if one were to crouch or try to shoot in a prone position. These difficulties have necessitated the need for extra support in situations when adequate support has been difficult to find. Herein I describe a lightweight, simple to use, and inexpensive rifle mount that will attach easily and quickly to any tripod. The adapter, once constructed, converts an ordinary camera tripod or monopod into a precision shooting support, thereby making it possible to make long range shots that might otherwise be missed without the stability of the tripod.

Materials necessary to construct the adapter include: 1 - 4-inch (10.16-cm) Acrylonitrile-Butadiene-Styrene (ABS) coupler, brown paint (flat paint for camouflage), green paint (flat), black paint (flat), 1 - 2-inch wide \times 12-inch long (5.08-cm \times 30.48-cm) piece of sticky-back tape Velcro, 25 ml clear epoxy, 1 - .25-inch \times .126-inch (6.4-mm \times 3.2-mm) coarse thread zinc bolt (beveled head), .126-inch (3.2-mm) Tee Nut and 1 set of black foam kneepads, or any foam insulation at least .37-inch (9.5-mm) thick. Although prices will vary, all of these items should be available for a total of less than \$12.00 U.S. There will also be left over material.

The ABS coupler is cut in equal halves and the concentric ring around the center of the coupling is then ground flat using a Dremmel® tool such that the surface is even all the way across; this also serves to roughen up the interior for the adhesive to bond the components together. A .31-inch (7.94-mm) diameter hole is then drilled in the ABS casing; the Tee Nut is placed into the hole from the outside and tapped lightly so that the spikes (for affixing in the Tee Nut in wood objects) leave an impression in the ABS. A .126-inch (3.2-mm) hole is drilled at the point of each impression. The Tee Nut is then glued from the inside with a small amount of epoxy and left to dry. Once hardened, the epoxy and the slight protrusion of the Tee Nut are feathered down flush with the body using the Dremmel® tool to prevent a bump from showing through the foam.

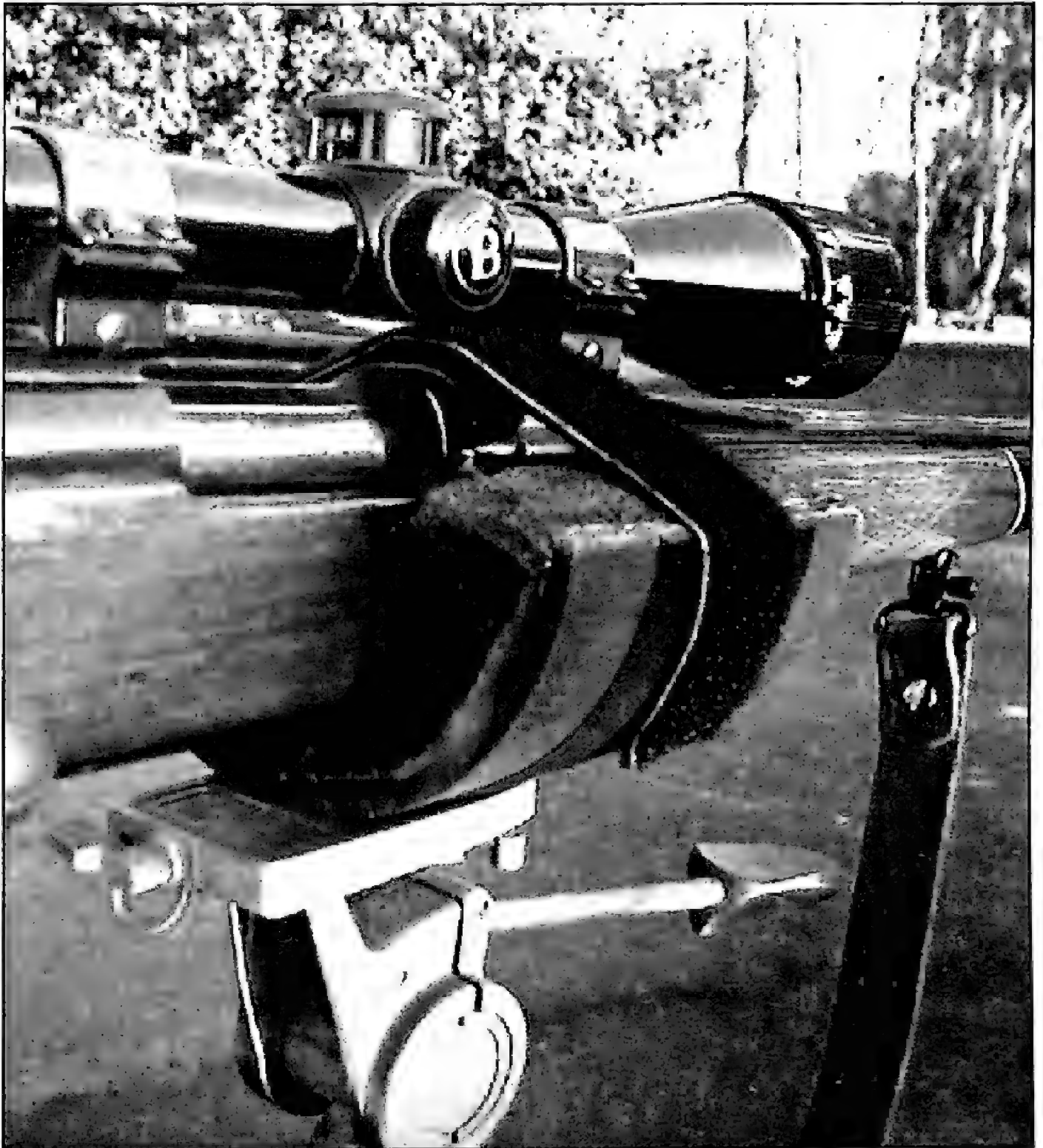


Figure 1. Assembled tripod rifle mount. Photograph by author.

Using the Dremmel® tool, both surfaces of the ABS are lightly sanded to ensure that the epoxy, once applied, will adhere to the ABS surface. A piece of a foam knee pad is pre-fitted and then glued to the channel: the kneepads already have a slight contour that will readily form to the ABS. Small "C" clamps can be used to hold the foam in place while the epoxy dries. After the epoxy has dried, the excess foam is cut off with a utility knife. This procedure is followed again, except that this time the layer of foam is glued to the inner sides only, over the top of the first layer of foam, such that a rifle will have a snug fit when in the device.

Any excess foam and dried residual epoxy, as well as the edges of the ABS, are then carefully rounded off with the Dremmel® tool. Then, using the sticky back tape of the 2-inch Velcro strips, the rough side of the Velcro is stuck to each side (outside) of the rifle mount. Following this, a piece of the soft side of the Velcro is cut and folded in half lengthwise such that it will stick to one side of the device and run over the gun barrel adhering to the other side of the holder (Fig. 1). Finally, the entire unit is covered with appropriate camouflage paint. The tripod can also be painted camouflage in order to hide what is normally a shiny aluminum reflectance.

The tripod rifle mount can be screwed on to the top of the tripod in the same manner as any camera or telescope. The tripod can be adjusted in exactly the same manner as it would for a camera or telescope to reach appropriate height and positioning. Before creating this device, ~66% of shots fired did not hit the target at distances ≥ 80 -m and ~25% of shots that did hit the target resulted in crippling the animal. Utility of this device has resulted in cutting the number of misses to $<15\%$ and has almost completely eliminated crippling shots. These improvements have resulted in minimal waste of ammunition, maximized productivity in the field and have, most importantly, minimized suffering.

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NEW RECORDS OF THE ALEUTIAN SKATE, *BATHYRAJA ALEUTICA* FROM NORTHERN CALIFORNIA

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The Aleutian skate, *Bathyraja aleutica* Gilbert, 1896, ranges from Hokkaido, Japan, throughout the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska, having been reported as far south as southeastern Alaska (Ishiyama 1967, Eschmeyer et al. 1983). In October 2000, a single Aleutian skate was collected at 40° N near Cape Mendocino, off northern California, approximately 1600 km south of earlier records. The specimen was collected by bottom trawl during the Alaska Fisheries Science Center's West Coast annual groundfish survey of the continental slope to assess groundfish and invertebrate abundance and distribution (Lauth 2001). The specimen (UW 040275, one immature male, 460 mm TL, 613 m depth, 5.2° C bottom temperature, 40° 23' 33" N, 124° 35' 28" W) is housed at the University of Washington Fish Collection, Seattle, Washington (Fig. 1).

The California specimen agrees well with the original and other descriptions of the species (Gilbert 1896, Evermann and Goldsborough 1907, Ishiyama 1967, and Eschmeyer et al. 1983). In life, the immature California specimen was brownish gray overall dorsally and white ventrally. The dorsal surface is entirely covered with small denticles and the ventral side is smooth without denticles. Meristics and morphometrics for this specimen are included in Table 1.

Many additional Aleutian skates collected off Oregon, Washington, and northern California from 1996-2002 by Alaska Fisheries Science Centers' groundfish surveys suggest that it is not uncommon along the U.S. west coast from Alaska to California and should be considered as an addition to the ichthyofauna for these areas (UW 040278, 1 male, (890 mm TL), 440 m depth, 5.9° C bottom temperature, 43° 42' 24" N, 124° 41' 22" W), (UW 040277, 1 male, (810 mm TL), 507 m depth, 5.4° C bottom temperature, 44° 18' 44" N, 124° 55' 05" W), (UW 040276, 1 male, (418 mm TL), 438 m depth, 5.4° C bottom temperature, 44° 24' 39" N, 124° 50' 28" W).

Other common species of *Bathyraja* that may frequently co-occur with *B. aleutica* off northern California include *Bathyraja interrupta*, *B. abyssicola*, *B. trachura*, *B. spinosissima*, and *B. parmifera*. *Bathyraja trachura* and *B. spinosissima* lack nuchal, scapular, and mid row dorsal thorns and have a black and gray ventral side, respectively (Miller and Lea 1972, Eschmeyer et al. 1983), where *B. aleutica* possesses these thorns and has a white to creamy ventral side with grayish margins. *Bathyraja interrupta* is similar to *B. aleutica* at small sizes but *B. interrupta* often has an interrupted row of

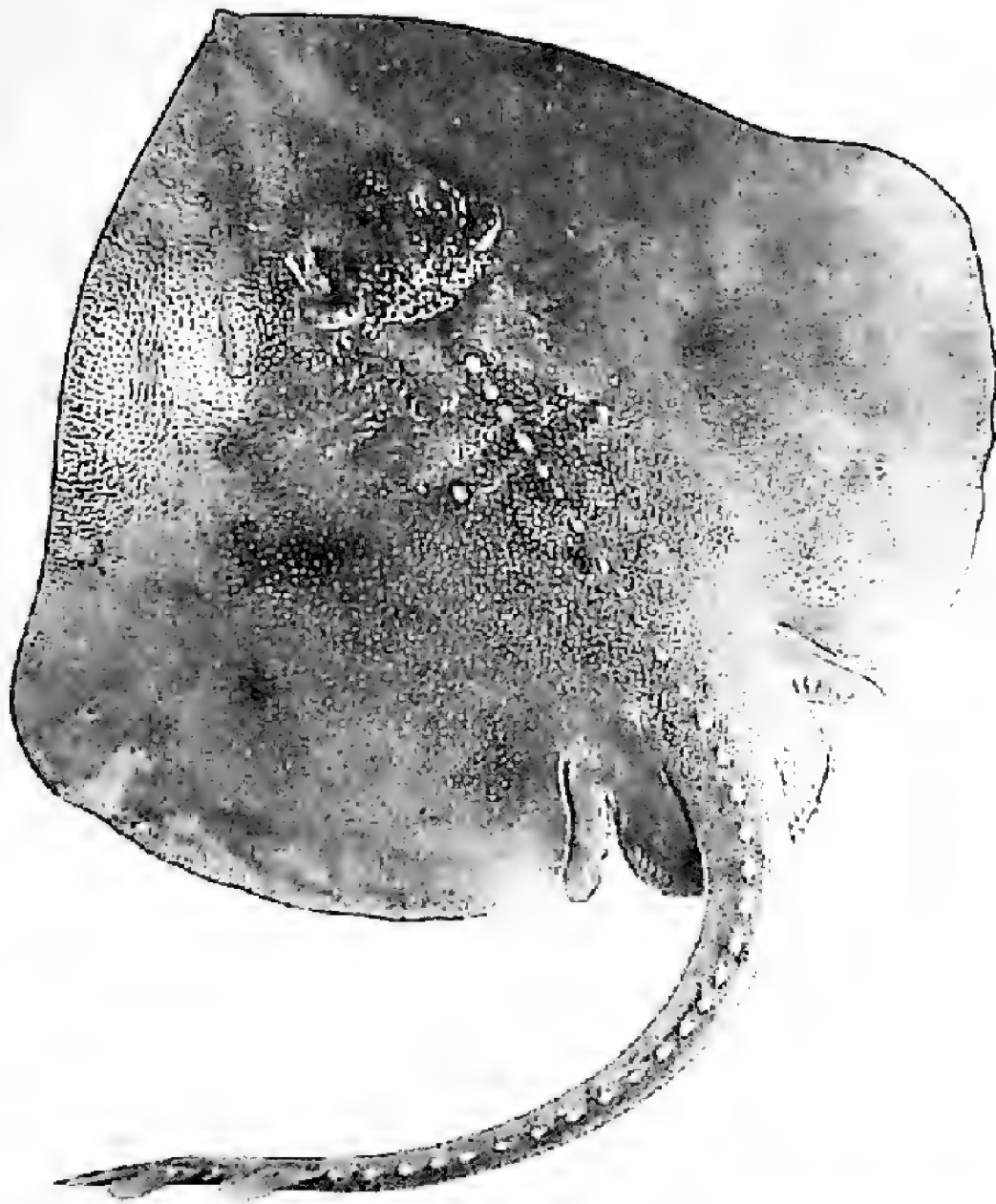


Figure 1. Dorsal view of the Aleutian skate, *Bathyraja aleutica* collected off Cape Mendocino, northern California in October 2000. (Immature male, 460 mm TL).

mid-dorsal thorns and the thorn size decreases along the length of the tail with 0-1 reduced inter-dorsal thorns, where *B. aleutica* has large thorns the length of the tail with 1-2 large inter-dorsal thorns (Mecklenburg et al. 2002). All three species (*B. interrupta*, *B. trachura*, and *B. spinosissima*) are smaller than *B. aleutica*, reaching <100 cm at maturity and generally having a more rounded body shape. *Bathyraja abyssicola* is similar to *B. aleutica* in body shape having a somewhat pronounced snout and achieving a large mature size of over 100 cm. However, the two species can easily be distinguished as *B. abyssicola* possesses small denticles and a grayish color on dorsal and ventral surfaces, and lacks scapular thorns (Mecklenburg et al. 2002). *Bathyraja parmifera* also can be distinguished from *B. aleutica* by the former possessing strong orbital thorns, dorsal surface not evenly covered with denticles at larger sizes, and the snout not notably pronounced (see Eschmeyer et al. 1983, Ishihara and Ishiyama 1985, Mecklenburg et al. 2002), where *B. aleutica* lacks enlarged orbital thorns and has a dorsal surface that is evenly covered with minute denticles at all sizes.

Table 1. Counts and Measurements of a single immature male *Bathyraja aleutica* specimen collected off northern California in October 2000.

Meristics

Nuchal thorns	4
Scapular thorns	2 (on each side)
Trunk thorns	7 (slightly reduced)
Caudal thorns	22
Interdorsal thorn	1 (strong)

Morphometrics

Total length (mm)	460
Disc length (mm)	210
Greatest disc width (mm)	273
Head length (mm)	95
Preorbital snout length (mm)	65
Orbit length (mm)	14
Interorbit width (mm)	22
Height of 1st dorsal fin (mm)	10
Height of 2nd dorsal fin (mm)	12
Tail length (mm)	250

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